THOMAS H. WIGGIN.

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1932—1933.

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THE ASSOCIATION was organized in Boston, Mass., on June 21, 1882, with the object of providing its members with means of social intercourse and for the exchange of knowledge pertaining to the construction and management of water works. From an original membership of only TWENTY-SEVEN, its growth has prospered until now it includes the names of 800 men. Its membership is divided into six classes, viz.:

A Member shall be an officer or employee of a public or private water works, an engineer, chemist or other person qualified to aid or interested in the advancement of knowledge relative to water works.

An Honorary Member shall be a person of acknowledged eminence in some branch of water supply or of engineering.

A Life Member shall be a member whose service to the Association entitles him to special recognition by the Association.

A Junior shall be not less than eighteen years nor more than twenty-five years of age, a student or connected with water supply work.

An Associate shall be either a person, firm or corporation engaged in manufacturing or furnishing materials or supplies for the construction or maintenance of water works.

A Corporate Member shall be either a Water Board, Commission, Company or Municipal Corporation.

The initiation fees and annual dues are as follows:

Initiation Fees		*Annual Dues*	
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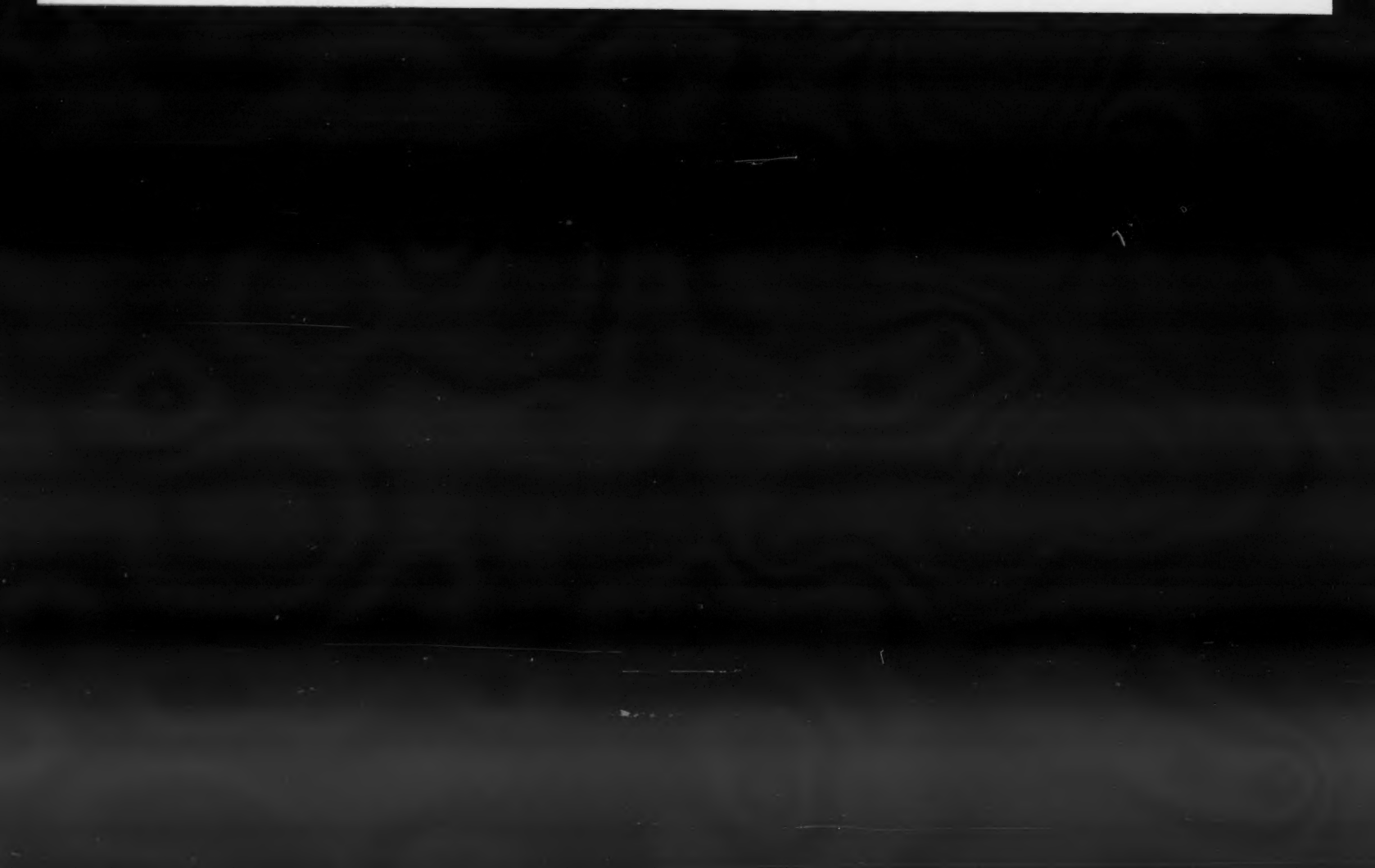

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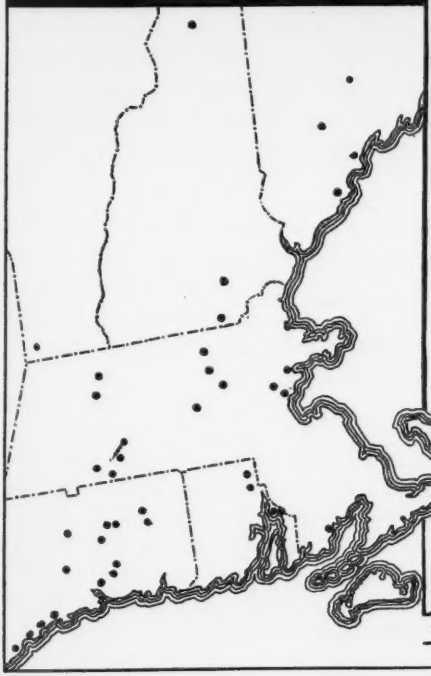

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LOCK JOINT PIPE JOBS

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New England Water Works Association

ORGANIZED 1882.

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This Association, as a body, is not responsible for the statements or opinions of any of its members.

AMERICAN AND ENGLISH WATER WORKS PRACTICE.

RANDOM IMPRESSIONS OF AN ENGLISH CHEMIST.

BY JOHN T. CALVERT.*

[*Read February 9, 1932.*]

As an inexperienced, though enthusiastic student of water-works practice, I am honored by the invitation to address the New England Water Works Association. Like the traditional visitor to any country, I have rushed about at every opportunity, and just as those of you who have been to Europe have probably seen more over there than I have, I have probably seen more of America than the majority of Americans. Perhaps, therefore, I shall be able to tell some things about England that are of interest and some things about America that are new. Many Americans do not realize how much there is to see out West because it is often simpler to take a boat to Europe after saving up for a long vacation. Europe may be old and England, especially to New Englanders, is historically inspiring, but I have seen nothing in England to compare in natural beauty with Yosemite Valley; and when I stood on the rim of the Grand Canyon, I experienced the most impressive moment of my life. This is away from the subject but the statement that there is a lot to see out West applies equally well to technical works as it does to the works of Nature.

I can probably best illustrate some differences in British and American practice by describing London's water-supply system, contrasting it with the problems which are encountered over here and explaining, as far as possible, the reasons for the differences. "Water London," which is served by the London Metropolitan Water Board, contains between 7½ and 8 million people within an area of 126 sq. miles. The city was not a settlement of the early Britons. The Romans who landed in the year 55 B. C. are responsible for its foundation. They constructed a bridge over the Thames where there had previously been a ford and used the Thames estuary as a harbor and port for their city of St. Albans, lying about twenty miles to the north, where their largest encampment was situated. The city of London owes its rise to power chiefly to its favorable situation on the Thames. In the first place the Thames provides an ideal inland harbor, sheltered and yet near enough to the coast to be easily accessible from the

*Commonwealth Fellow at Massachusetts Institute of Technology.

Continent. Nowadays a city can rise even where the natural supply of water is not abundant. The technique of pipe-line and tunnel construction has been so elaborated as to enable, for example, the growth of many of the cities on the southern Pacific coast. Previously a good local water supply was essential to a city, and London in this respect was well placed. Not only was the Thames the second largest river in England, but there were also in the district innumerable fresh-water springs rising throughout the city from the London Gravel.

From a water-works point of view climate is a very important factor. In my opinion it is one of two or possibly three important reasons for the differences in American and British water-works practice. The weather is generally considered a good topic for introducing conversation, but to a water-works engineer it is far more than a commonplace. In England, water-works men are perhaps the only class benefited by British weather; even then they do not appreciate how fortunate they are. In the first place, the Gulf Stream flowing past the coast moderates the temperature of the island. The mean annual temperature is 50° F., and there are no extreme variations from it. The winter averages somewhat above freezing, and a drop of 10°F. below freezing causes extensive newspaper comment. Similarly in summer, if the thermometer rises much above 80°F. everyone begins to complain, and the press talks about the hottest day on record. This accounts for certain minor differences such as the fact that we have no post hydrants but use flush hydrants which are never buried by deep drifts of snow. Pipes do not need to be laid deep to prevent freezing and I hardly think that there is a covered slow sand-filter in England; yet they operate throughout the year and no precautions need be taken to obtain a cool supply, as our streams seldom become unpleasantly warm. The comparatively steady temperature explains, I think, the consistent difference in water consumption per capita. In America 100 gal. per head is generally taken as a rough guide, although there are some big cities like Chicago and Buffalo which use more than twice this amount. In England, the corresponding figure would be set at 40 or 50 gal. Yet I think English people are almost as clean, although in the absence of many hot, dry days there is not so much bathing. Little water is used for sprinkling lawns. Here this use seems to account for a large proportion of increased summer consumption. In winter it seems that considerable quantities of water are wasted in America to prevent the freezing of pipes, while in England the danger of freezing is restricted to short periods. The temperature, therefore, favors the English water-works engineer. The rainfall, too, is on his side. Although in London the annual rainfall is only 24 inches, it is more evenly distributed through the year than in most parts of this country, with New England as a possible exception. This means that our rivers seldom dry up; also that they are rarely too turbid for water to be drawn from them. Consequently less water is "wasted" by flood flows, unwillingly into the sea. This simplifies matters in two ways. In the first place

not so much water storage is required to ensure adequacy of supply and secondly, the water can be gathered from smaller catchment areas. This is an important consideration when we realize that the density of population in England is about 700 to the square mile, compared with less than 600 in Rhode Island, the most densely populated American state. The problem, therefore, of finding satisfactory pure sources of supply would be almost insoluble were it not for the fact that smaller watersheds are capable of supplying the demands of the population. I must mention London's fogs because most Americans imagine that London is one thick fog throughout the winter, whereas fogs only occur three or four times a year. When one descends, however, it is blacker and more objectionable than it is possible for a foreigner to conceive of,—so thick that traffic is reduced to a walking pace and lighted street lamps cannot be seen across the road.

The first commercial enterprise to supply water to London started in 1581 when Peter Moris, a Dutchman, put a pump under London Bridge and forced water into the city. This continued as a flourishing business until the beginning of the last century when a number of rival companies amalgamated and took this company in with them. The first competitor sprang up in the seventeenth century, when Sir Hugh Myddleton constructed an aqueduct 38 miles long to carry water from springs in Hertfordshire, north of London; this water was later supplemented by water from the River Lee, a tributary of the Thames. These corporations were so profitable that they attracted others, but the new companies had nothing new to offer and only differed in the points where the water was withdrawn from the Thames and in the districts supplied by the companies. One other source of supply was tapped, namely, a number of deep wells in Kent, south of London. This is still an important source.

In 1829, an innovation introduced by Charles Simpson, Engineer to the Chelsea Water Works Company, practically revolutionized waterworks practice and laid the foundations for the elaborate treatment works of the present day, namely, the construction of the first sand filter to improve the supply. The development of sand filtration seems extremely interesting, especially when one studies the cycle through which the theoretical aim of filtration has passed. Originally the filters were designed merely to improve the physical appearance of the water. Even when the river was slightly turbid, the product from a sand filter was clear and sparkling, and so the use of filters became more and more popular. Later, with Pasteur, and the rise of the science of bacteriology and with the general acceptance of the germ theory of disease, we have an entirely new conception of the purpose of sand filtration. This originated perhaps with the cholera epidemic in Hamburg in 1892 when Altona, a neighboring community which used the same source of supply, the Elbe River, but filtered the water before distribution, did not suffer to anything like the extent as Hamburg which used the raw, untreated water. Experiments showed that sand filtration removed 99.9 per cent. of the bacteria from a

polluted water. This fact led to this new purpose of filtration. While it was still appreciated that filtration improved the appearance, the arguments advanced in favor of it were chiefly those of conserving the Public Health. It is claimed that everything moves in cycles; we have certainly returned now to the original idea of filtration, especially here in America. Filtration is again advocated for its improvement of the physical quality of the water, and disinfection, especially by chlorination, is regarded as the modern safeguard of the Public Health. This change has resulted, too, in the extensive use of rapid sand-filtration.

Early experiments indicated that bacterial removal by rapid sand-filtration is not nearly so high as by a slow sand-filter. This retarded their development until chlorination was introduced about 1904 and the same ultimate result both as regards appearance and safety could be attained more cheaply and in a smaller space. The first rapid sand-filter was constructed in Somerville, N. J., in 1885, but this and other early plants were employed to improve the quality of water which was in its natural state relatively innocuous.

In the historical development of sand filtration, and especially in the precise period at which it took place in the two countries, I think we have another fundamental cause of the differences of water-works practice here and at home. In England, pure sources of supply were becoming more and more difficult to obtain, so that the introduction of filtration was followed by very rapid growth after its health-protecting powers had been demonstrated. In this country, the necessity for immediate treatment of water supplies was not nearly so urgent. The rivers here are much bigger and on account of the less dense population, far less polluted, and most cities could find a suitable uninhabited watershed in the vicinity from which they could draw their supply. Hence, here in America there was not the fervid installation of slow sand-filters that occurred in England. Consequently many English communities had their slow sand-filters already constructed at the time when rapid sand-filters became sound scientific practice. In America, on the other hand, the rapid growth in population occurred at the end of the last century and at the beginning of the present century, and is still in progress though today at a somewhat slower rate. Pollution did not become a real menace to the people until the early nineteen hundreds. Soon afterwards the use of liquid chlorine was introduced, and chlorine was manufactured so cheaply as to make it the perfect disinfectant. Hence, with a cheap disinfectant and newer knowledge and experience of filtration, the conditions were ideal for the introduction of rapid sand-filtration on a large scale. Couple with this the facts that money was available for development, and that American cities tend to vie with each other in the up-to-date character of their public utilities, and the much more frequent use of rapid sand-filtration in this country becomes understandable. It is true, too, that rapid sand-filtration is more suitable for American waters than for British waters. I have been quite impressed by the very

turbid nature of some waters which are treated and delivered as potable drinking supplies. In New Orleans the turbidity of the Mississippi may rise above 2 000 p.p.m., yet the plant turns out a clear effluent; the Colorado River, which has been described as being "too thin to plough, but too thick to drink," is now being treated for use in the new Boulder City on the construction of the Hoover Dam. But even in New England, where turbid waters are not encountered, any new plant, as for example that at Providence, is of the rapid sand type and it seems doubtful whether new slow sand-filters will ever be constructed. In England, money is tied up in existing slow sand-filters and more is not available, especially during the present strained condition of British finances, so that it is not sound economics to replace them by rapid filters. New plants, however, are now of the American type. In London rapid sand-filters are being extensively utilized in order to increase the rate of filtration through the slow filters already in existence.

This would indicate, and it is certainly true, that the later the development takes place, the more advantageous is the position of a country; but delayed development in the water-works field may be disastrous to the Public Health, and too premature construction is not advisable on account of the possibility of the application of newer knowledge. It is conceivable that in the future some new discovery may change the methods of water purification and that cities like Boston, at present without treatment works, will then be able to adopt these means when purification becomes essential and so lead the field as a result of postponed necessity for construction.

Like London, most other British cities use surface-water supplies and endeavor to obtain them from regions populated as sparsely as possible. Glasgow is fortunate in having Loch Catrine in the neighborhood which furnishes an apparently inexhaustible supply, and Liverpool has constructed a large dam in North Wales to care for its requirements. Birmingham, too, obtains its water from North Wales and Sheffield from almost uninhabited regions in Yorkshire. London is in a peculiar position because its source of supply is by no means pure and the Thames basin takes the sewage from many upper communities, some of them of appreciable size. This pollution of the Thames first became serious enough to warrant action in 1854 when the water companies were forced by act of parliament to move their intakes above the tidal portion of the river. The problem is becoming more difficult every day. A recent proposal to build a huge treatment works for the sewage of the whole of Middlesex, at times equal to the natural flow of the river, has inspired A. P. Herbert to write the following as a substitute for the various poems written to the Thames:

> Sweet effluent, dear Father Drain,
> Whose generous bosom doth contain
> A lot of oil, a little rain,
> And all the muck of Middlesex.

The pollution is being prevented as much as possible, but it is impossible to avoid it entirely with such a thickly populated watershed. There are two possibilities in the future of London's supply when water demands increase and the pollution becomes even worse. The first is greater storage, and in that direction the reservoir capacity has been increased fourfold since the inception of the Metropolitan Water Board in 1903, so that there is now storage of 20 billion gallons, calculated to be adequate until 1940. The newest London reservoirs, I think, are unique in that they have no assistance from Nature. There is no natural gorge around London across which a dam can be thrown, and these reservoirs are constructed merely by building a dyke around a huge plot of land. The Queen Mary reservoir, completed in 1925, has a capacity of 6½ billion gallons, is surrounded by a four-mile dyke and covers an area of 723 acres.

The second proposal to combat the dangers of the polluted Thames has been its entire rejection as the source of London's water, and the substitution of the Welsh hills as the catchment area. At the time of the Royal Commission which inquired into the London water question, Sir Alexander Binnie, then chief engineer to the London County Council, showed that it was quite feasible to construct an aqueduct across England to bring water into a reservoir north of London and that it would provide a purer and more adequate supply. This scheme, although rejected by the Commission, may still have a future, especially when one considers the enormous aqueducts and water tunnels which have been so successfully built in this country. At present nearly 60 per cent. of London's water is extracted from the Thames, 25 per cent. from the River Lee and the rest from deep wells in Kent. All of the water is filtered through slow sand-filters,—some after pretreatment through rapid filters,—and is chlorinated only as occasion demands.

There are various other aspects in connection with the operation of filtration which have impressed me as I have visited plants in this country. The first is the importance of mixing after the addition of coagulants. Go to Mr. Bean in Providence or Mr. Hoover in Columbus; both will show conclusive laboratory experiments illustrating the gradual formation of the floc on stirring. I think it is safe to say, therefore, that an adequate mixing period not only saves chemicals but also materially lengthens filter runs. I have also been struck by the introduction of mechanical devices into water-works practice and the installation of remote control into most of the newer plants. It seems to me an ideal state of affairs when every pump or dosing device can be operated from the same switchboard and there are at the same time continuous mechanical recorders both of the pH and of the turbidity of the effluent. It seems, too, that determined efforts are being made to combat obnoxious tastes and odors. The numerous experiments being tried should lead to interesting and conclusive results. Somehow success seems to depend markedly on the character of the water to be treated, and it is impossible to predict whether a given method will

succeed or not. Prechlorination in conjunction with ammonia is being employed satisfactorily in Indianapolis, and the use of ammonia with chlorine appears to solve the problem in many cities. Unfortunately, I have not seen any plant using active carbon, but it is always reported as being successful, with cost and inexperience as its only drawbacks. I have been interested by the municipal plants practicing water softening, since in England softening is done mostly by those industries which absolutely require it. I was especially favorably impressed by a plant for a city of 20 000 in Ohio where the water is softened by lime, put through rapid sand-filters and part softened by zeolite filters so as to get a final effluent of just the desired hardness. The whole was controlled automatically, even to the lime dosing, depending upon the flow. The proportions of lime-softened and zeolite-softened mixture were controlled by a Venturi meter. I was told that during a recent power failure in the city one inhabitant went immediately to the faucet, saying, "if I can get a drink now, then that new plant must be a good one"; the plant building was the only one in the town which was illuminated at the time.

There is one other feature which, although it borders on sewage disposal, has so fascinated me and was so new to me, that I must mention it now. That is the question of water reclamation. In England it has hardly been heard of, and in New England it is not considered seriously, but out in the West it is a pressing problem. The objections to it are solely esthetic, and it is actually what happens in many rivers both here and in England. Yet the most hardened scientist admits that the objections are valid, and no one has yet been bold enough to advocate the return of reclaimed water to the distribution system. There are two plants, which I saw, where reclamation is definitely in operation. Apparently both work successfully and without causing complaint. The first was at the Grand Canyon of the Colorado. Here all the water has to be carried into the National Park in tank cars, each carrying 10 000 gal. a distance of 120 miles at a cost of $3.09 a thousand gallons. The waste water can be treated completely, including operation of a miniature activated-sludge plant, filtration and chlorination at a cost of 39 cents per thousand gallons. It is then, to all external appearances, a perfect potable water. The reclaimed water is pumped into a separate distribution system which is carefully painted a different color and is utilized for power and condenser purposes, irrigation, locomotives and flushing toilets. Careful precautions are exercised to prevent its use for any other purpose. The other plant was the experimental plant designed by Mr. Goudey in Los Angeles where water is a precious commodity, though not so valuable as in the Grand Canyon. This plant takes about a quarter of a million gallons daily from the main Los Angeles sewage outfall and treats it just as thoroughly, including the use of a carbon bed but here, instead of being piped away it is allowed to percolate into the ground-water strata from which Los Angeles obtains a portion of its water supply. No one raises objection to either of

these processes, and it is possible and reasonable that the Los Angeles plant will be extended up to a much larger scale. Yet the idea of reclaiming sewage in this way, carried to its final and logical conclusion, will immediately cause an uproar.

These examples would seem not to concern New Englanders, but there are plants which bring the problem much nearer home. Tenafly, N. J., is on the catchment area of a large water company and the sewage-treatment plant of the borough, designed by Fuller & McClintock, including activated-sludge treatment followed by sand filtration and chlorination provides the most perfect disposal that I have seen. The quantity of water is a small proportion of the water company's total consumption so that the example cannot be considered a case of reclamation, but I mention it as leading to a Utopia where nothing but perfectly treated waste water is discharged into our streams and the position of water-works engineers is one of the simplest in the land.

I should like to conclude by mentioning how hospitable everyone in America has been to me, and by thanking the New England Water Works Association for its kindness.

Discussion.

E. Sherman Chase.* The last thought which Mr. Calvert left with us was that of "reclaimed water." Such water may be all right when it is impossible to get anything better, but we in New England continue to prefer original sources as free from original sin as possible.

I had opportunity this last summer to see some of the English water-works systems and was impressed with some of the developments taking place in England. We are likely to think that all good things in public works and engineering originate in America, or that we have the start on the slower Europeans, so-called, but as a matter of fact, in many respects England has been ahead of us in our water-works development.

This matter of chlorination, which we sometimes think of as an exclusively American institution, was originated on a large scale, in a practical way, by Sir Alexander Houston at the Lincoln water supply in 1905. The slow sand-filters which were started in Lawrence in 1893 were antedated by the Chelsea filters on the London supply in 1829. We did beat the English in the use of rapid sand-filters. They still use such filters, particularly in the case of the London supplies, as prefilters without the application of a coagulant. This is not universally true in England, as a number of rapid sand-filters do use a coagulant.

Mr. Calvert spoke of not having seen in this country any plant using activated carbon. I saw one plant, the South End Water Company, a few miles out of London, where activated carbon is used as a regular process in

*Of Metcalf and Eddy, Consulting Engineers, Boston, Mass.

the treatment of the supply, the carbon being applied to the water after coagulation and sedmentation, just ahead of the filters.

Mr. Calvert also spoke about the comparatively little use of water-softening plants in the British Isles. As a matter of fact, at this same plant where activated carbon is being employed the water is softened by the excess lime method, similar to that being used in Columbus, Ohio. A particularly interesting development in this plant is the recovery of the lime sludge. For each pound of lime applied for softening another pound of lime is taken from the water, so that, roughly, two pounds of lime are produced for every pound used. This lime sludge is lagooned, and at intervals the sludge from the lagoons is calcined in a gas-fired rotary kiln. A portion of the quick lime is later hydrated, and the hydrated lime is sold to the farmers. The rest of the lime is used in the process over and over again.

There are many interesting developments in England, and many interesting public water supplies for an American visitor to visit. I feel that it is a real education in water-works engineering for an American engineer to go to England and see what they are doing there.

ROBERT SPURR WESTON.* We are delighted to have Mr. Calvert tell us the interesting things about water-works practice in England and America, and all of us agree that he has been a careful observer. Mr. Calvert, as most of you know, is the son of a distinguished scientist, Dr. Calvert, Chief Engineer of the Ministry of Health in England. I think that all of us who have known of the works of the father are pleased to have the son with us.

As I sit here with some of the younger members of the Association, I am reminded of the fact that I have been a member for over thirty years. I am also reminded that in 1897, when Mr. Hazen and I were in London and called on Mr. William Ryan, Superintendent of the East London Water Company, we were shown a great curiosity, some pictures of ice that had been taken from the water on the filter beds belonging to that company. In this country experience has shown that covers are necessary.

The urge toward the use of filters in England was to improve appearance, not, as is generally the case in this country, to reduce color and turbidity, but to remove the suspended vegetable and organic matter which is common in New and Old England and uncommon in the great West. This consideration of appearances, I think, is increasing among us as our standards of water quality rise. Thirty years ago no one would question the quality of water having a color of 40 or 50 p.p.m., yet now the United States Public Health Service sets as a standard a color of 10 p.p.m. or less. That is a color not noticeable in a tumbler, but still noticeable in a bath tub. People dislike to drink water which is supplied from many of our upland reservoirs because it is colored; and colored water, in my opinion, whether chlorinated or not, has had its day.

*Of Weston and Sampson, Boston, Mass.

After all is said and done there is nothing like storage to purify water. That is what we have depended upon in New England, largely; but we have to change our point of view with respect to storage. The automobile is taking more and more picnickers to upland sources, which we long considered "innocent" and more and more we have to consider the question of "repentance" in regard to water; we cannot always do as we have done.

Chlorination, with all its excellences has some disadvantages. When water contains a great deal of organic matter, objectionable tastes often follow chlorination; tastes which cannot be removed by chlorination in combination with ammonia treatment.

Activated carbon treatment is useful in conjunction with chlorination. Quite recently we have introduced activated carbon in three plants, where they are using only four pounds of carbon to a million gallons. The cost of so treating this water is not great. Carbon treatment is a useful tool where waters possess disagreeable odors and tastes which cannot be removed by ordinary coagulation followed by filtration through rapid filters.

As to filters themselves, the old English filters were rather thin and had coarse sand. The modern English filter is a very efficient device for purifying water, and in these days when one can employ rates of from six to eight million gallons per acre a day and use chlorine as an additional line of defense, there is much to be said in its favor, especially in towns of 10 000 population or less. In a town of this size it is difficult to hire and keep the necessary attendant to run a rapid filter. The experience of our firm is that the use of automatic devices for feeding chlorine and sulphate of aluminum must be depended upon to adjust the dose of chemical to the water in rapid-filter plants for these small towns, in which one recommends rapid filters with more and more hesitation until devices for automatic control are better developed and are more reasonable in cost. Slow filters, therefore, remain useful for purifying many waters and have a great deal in their favor. The day has gone by when one can find many supplies for which storage alone will provide the proper quality of water, and one must depend more and more upon artificial methods of purification for the supplies of our cities. If we consider what is being done in London, as Mr. Calvert has said, where water is not only chlorinated but filtered and stored, and what is being done in some parts of this country where storage is impossible, we realize that artificial methods must be relied upon more and more. Nevertheless, long storage is still the best single method of purification we have.

In a recent public controversy in New Jersey, certain parties were complaining about the pollution originating at a popular lake resort, yet the water of this lake would be purified by storage for 540 days followed by an additional 108 days in a storage reservoir. This condition shut off absolutely any chance of pollution from the primary source. The desire to remove such remote sources of pollution from water must be exercised with reason. It is good sanitary practice to get water from as pure a source as one can and then to purify it to the degree that is necessary.

ARTHUR L. SHAW.* When Mr. Calvert prefaced his remarks by the statement that perhaps he had failed to observe in his mother country many of the things that might be apparent to a visitor from America, I started to jot down a number of things I had noticed in connection with English water works, but I have had to cross out one after another while listening to his talk. I think he was too modest in his statement. There remain, however, three or four items which may be of interest.

Mr. Calvert mentioned that open slow sand-filters were used to a great extent. That is very noticeable to a visitor; it is also noticeable that around some of them, especially toward the north of England and in Scotland, there often are feathers on the ground. On inquiry I found that for many years operators have been in the habit of shooting the gulls and other birds that come to feed upon the aquatic growths that develop on these open sand-filters. Apparently English water-works men have long since used this means of protection which has only recently been made possible in Massachusetts by legislative authority.

The low rate of consumption, at least in Edinburgh, may be explained partly by the close control which is maintained upon the fixtures and types of fixtures that are used. In that city, not merely every type of fixture, but every fixture itself, has to pass through the inspecting shop of the water works and receive a stamp of approval; the use of any faucet or other fixture not bearing the stamp of the local water works is not permitted, so that the chances of leaky fixtures and loss of water by that means are minimized.

The watershed of the Bradford Water Works reservoir, lies in a territory in the upland moors that is almost completely barren of trees. I inquired whether anything had been done in the way of reforestation, and found that many experiments had been made and that it had been found that, although the rainfall is apparently adequate to support the growth of trees, there are other climatic reasons, primarily altitude, which have made the attempts at reforestation of this watershed unsuccessful. The low cover of heather, bracken, and the like must be depended upon to protect the soil of this and similar watersheds.

The matter of compensation for the taking of water for public purposes is an interesting one. As I understand it, over a long term of years there has grown up what has become almost standard parliamentary practice whereby in granting diversion rights virtually one-third of the run-off of a stream must be released for the maintenance of flow in the stream below the water-works intake. This amounts to dedicating one-third of the watershed to the maintenance of flow below the dam. This requirement has worked a great hardship in many cases because of the empirical rules by which the amount of compensation water is computed in the absence of long-term run-off records. A special committee of engineers has been working on this subject under the auspices of the Ministry of Health, attempting to clarify

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and reduce to a more logical basis the method of computation. The proposed solution has been covered at some length in a published report entitled "Ministry of Health, Advisory Committee on Water, Report of Technical Sub-Committee on the Assessment of Compensation Water." The committee clings in general to the basic principle of deducting approximately one-third of the flow, but it proposes to modify the methods of determining that quantity by a very careful analysis of the rainfall and run-off records and by the application of factors determined from the characteristics of the particular stream, whether flashy or uniform, and from the degree to which the given stream has become industrialized. If this report has not already been accepted by Parliament, it is only a question of time before the English principle of compensation will be reduced to a logical basis which can be applied to each case and reach results far more equitable than in the past.

LINN H. ENSLOW.* I think Mr. Calvert is far too modest in his claims for English practice. I happen to know that activated carbon, and the use of it for water treatment, was developed in England over twenty years ago, and he claimed nothing at all for this English contribution. I want to place on record the fact that activated carbon was first employed for water treatment by the Candy Filter Company in England over twenty years ago. It was used in pressure-type filters in addition to the sand and gravel.

GORDON M. FAIR.† Mr. Calvert has shown very clearly why waterworks practice in England differs in many essentials from that in the United States. Most of the differences, apparently, can be explained either on the basis of "other climes, other customs," or on that of "age without obsolescence." There is one other major factor, however, to which attention may be called. This is the difficulty of acquiring in England the type of training which can be obtained in this country in universities or scientific schools under the name of "sanitary engineering." Mr. Calvert's own study in this country testifies to this situation.

This statement does not imply, however, that we are the sole possessors of the ultimate good. Both countries have done their share in advancing the science as well as the art of water-supply engineering and management. Each can learn from the other, and each in turn will find it worth while to extend a welcome to the visitor from across the sea.

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†Associate Professor of Sanitary Engineering, Harvard University, Cambridge, Mass.

MEASURES ADOPTED FOR THE CONTROL OF TASTES AND ODORS DUE TO THE DEVELOPMENT OF MICROSCOPIC ORGANISMS IN SPOT POND RESERVOIR, BOSTON METROPOLITAN DISTRICT.

BY SAMUEL E. KILLAM.*

[*Read May 11, 1932.*]

Conditions arise in almost every water supply which require unusual measures to deliver palatable drinking water to the consumer. One such condition arose in Metropolitan Boston early in 1932 when one of the largest growths of *Uroglenopsis* ever recorded for the reservoirs of the Boston Metropolitan District Supply developed in Spot Pond, a reservoir from which water is pumped for the northern high-service district. This district comprises the higher areas of Somerville, Medford, Malden, Everett, Chelsea and East Boston, and all of Stoneham, Melrose, Revere, Winthrop, Swampscott and Nahant, including an estimated population of 192 000 and supplied with an average of 12 m.g.d. of water.

Spot Pond, the largest distributing reservoir of the Metropolitan District, is located in Stoneham and Medford, about six miles from the State House in Boston, and has a storage capacity of about 1 800 m.g. The reservoir was developed from a natural pond by building dams and dikes, which raised the water level about nine feet. The material for constructing the dams and dikes was, for the most part, excavated from the areas of shallow flowage of the pond so as to establish a uniform depth of about fifteen feet at high water. Large areas within the reservoir where mud pockets were deep were covered with about twelve inches of sand and gravel. A drainage system was constructed to care for the area draining immediately into the pond. For the most part, water from the original watershed is thus prevented from entering the reservoir. It is probable that the water collected from this area would not be suitable for domestic use; so it is bypassed and discharged into a brook which was the natural outlet of the pond. Two concrete masonry chambers, located about 3 000 ft. apart on the shores of Spot Pond, contain the sluice gates that regulate the flow of water. The water enters or leaves the pond through two inlets from the chambers at different depths. From the east chamber a concrete masonry conduit, 5 ft. high and 4½ ft. wide, extends 565 ft. into the pond. This inlet is 25.2 ft. below high water. There is also a 48-in. pipe, 58 ft. in length, which serves as the high-level inlet 12 ft. below high water. From the south chamber two masonry conduits, one above the other, extend 200 ft. into the pond. The invert of the lower conduit is 26 ft. and the invert of the upper

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conduit 12 ft. below high water. The two chambers are connected to cast-iron mains of the low-service district. (See Fig. 1.)

On the easterly shore of Spot Pond, near the gatehouse, is located the high-service pumping station which, from necessity, must receive the supply for its pump wells from Spot Pond. This station pumps all the water

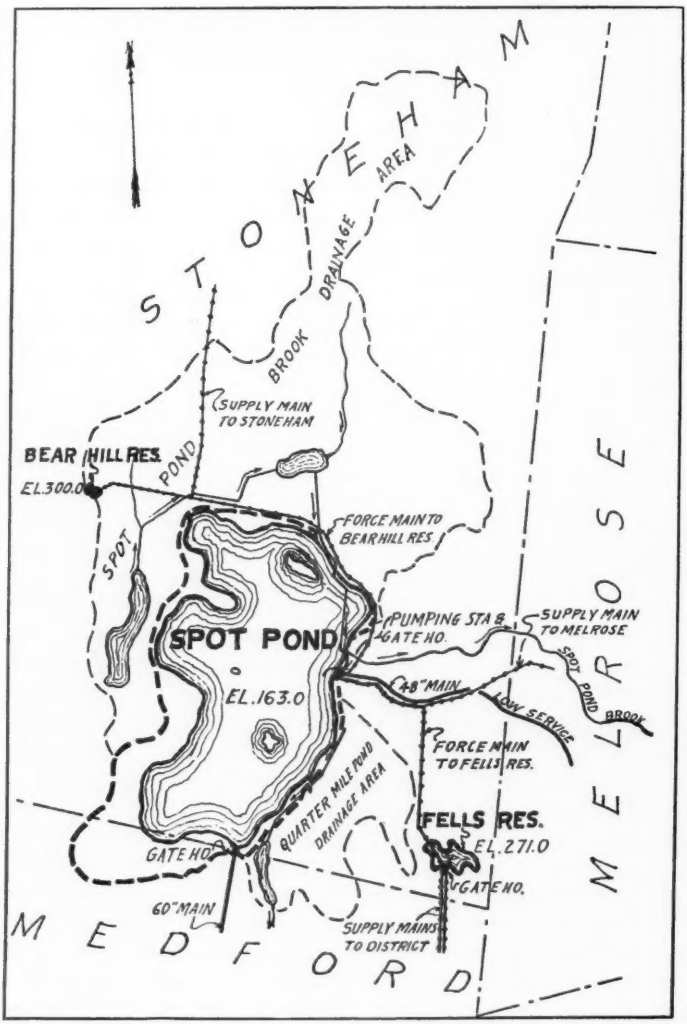

FIG. 1.—GENERAL MAP OF THE SPOT POND WORKS, METROPOLITAN DISTRICT WATER SUPPLY OF BOSTON, MASS.

for the northern high-service district, with the Fells Reservoir and Bear Hill Reservoir as storage and distributing reservoirs. (See Fig. 2.)

The Fells Reservoir, having a capacity of 41½ m.g., is located in the Middlesex Fells Reservation in the town of Stoneham, about half a mile east of Spot Pond, and its high-water line is 108 ft. above the level of Spot Pond. The reservoir is connected with the pumping station by a 36-in. force main and with the service in the northern part of the Metropolitan

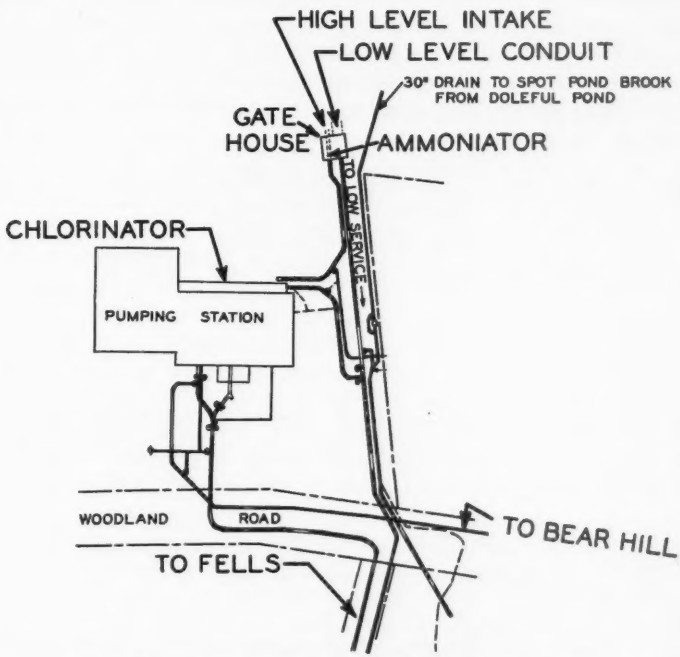

FIG. 2.—INTAKE WORKS AND PUMPING STATION ON SPOT POND.

District. Below elevation 265 ft. (Boston City Base) the Fells Reservoir is divided into two basins, and the pipes and valves are so arranged that Spot Pond water can be supplied directly to the consumer through the gate-house or pumped into either basin.

Bear Hill Reservoir, having a capacity of 2½ m.g., is located in the Middlesex Fells Reservation in the town of Stoneham, about one-third of a mile west of Spot Pond, and has its flow line at elevation 300 ft., or 29 ft. higher than Fells Reservoir. This reservoir is used at present for supplying water to the town of Stoneham, and water comes to it from the pumping station at Spot Pond through a 24- and 20-in. force main.

In the past, the people receiving Spot Pond water have always been pleased with its quality as it has been practically free from offensive odors and tastes caused by microörganisms. Thus relations between the District Commission and the people of this area have been very cordial for a number of years. The color of the water has usually been between 10 and 20 p.p.m. The cold odor has generally been reported as "slightly vegetable" and the hot odor at its worst as "slightly unpleasant" and "earthy."

Growth of Microscopic Organisms. During the year 1931 a growth of *Synura* was noted in late September which increased to about 7 500 areal standard units per c.c. in early October. *Synura* disappeared late in October and was followed by a growth of *Uroglenopsis* which continued through the remainder of the year, varying in amount from 1 000 to 3 500 standard units per c.c. in November and December, giving off an oily,

TABLE 1. — BIOLOGICAL EXAMINATION OF SAMPLES OF WATER COLLECTED FROM SPOT POND, FEBRUARY 2, 1932.

C. E. LIVERMORE, BIOLOGIST.

Sampling Location.	Color p.p.m.	Hot Odor.	Total† Organisms.	Diatoms.†		Protozoa.†		
				Total.	Asterionella.	Total.	Dinobryon.	Uroglenopsis.
South end.....	10	Decided*	3 072	1 303	1 172	1 765	55	1 706
West side.....	10	Decided	3 222	1 281	1 080	1 929	115	1 800
North end	10	Decided	3 434	1 356	1 166	2 072	110	1 950
East side	10	Decided	2 885	852	766	1 959	55	1 880

*Decided — An odor that would force itself upon the attention and that might make the water unpalatable.

†Organisms in areal standard units per cubic centimeter.

fishy odor when hot. Complaints from consumers were persistent but not numerous or serious during this period. Early in January 1932, in addition to the growth of *Uroglenopsis* other objectionable organisms made their appearance, especially *Dinobryon* and *Synura*, and the odor from the hot water became objectionable.

This condition continued through the month of February, complaints from consumers becoming numerous and serious, and it was decided to treat the waters of Spot Pond in an endeavor to remove the tastes and odors as the preventive stage had already passed. The pond had frozen over before preventive measures could be applied.

Ammonia-Chlorine Treatment. We were advised that chloramine which could be produced by applying ammonia and chlorine to the water before it entered the pumps would be effective in destroying the organisms. We were also advised that ammoniation prior to chlorination would pre-

vent a chlorinous taste which sometimes becomes very disagreeable when it is combined with certain tastes and odors produced by microscopic organisms.

Wallace & Tiernan ammonia and chlorine controllers were installed in the gatehouse and pumping station on the shore of the reservoir and placed in service on March 3. The ammoniator, located in the gatehouse, discharged ammonia into the water supply about 200 ft. before it entered the pump well in the station. The portable chlorinator, installed in the basement of the pumping station, introduced liquid chlorine into the suction of the pump. The pump was operated at a rate of about 11 m.g.d., pumping during 24 hours into Fells Reservoir and during about 6 hours into Bear Hill Reservoir. The city of Melrose receives all its water directly from the force main to Fells Reservoir, and the town of Stoneham, during about 6 hours of the day, is supplied directly from the force main to Bear Hill Reservoir.

We were advised that one of the most important factors in the use of the ammonia-chlorine process was the point of application of the ammonia. This should be sufficiently far from the point of application of the chlorine to permit thorough mixing of the ammonia with the water and yet not so far as to permit microörganisms to consume it before the chlorine is introduced.

The dosages of ammonia and chlorine employed had to be determined by experiment and were gradually increased while samples taken from the distribution systems were tested for improvement in taste and odor. Table 2 gives the amounts of chlorine and ammonia which were introduced into the water supply during the time that chloramine was used in an endeavor to improve conditions. The residual chlorine content of the water is shown in Table 3.

The ammonia-chlorine process did not prove a cure-all for our taste difficulties but considerable improvement due to its use was noted while we were maintaining a high residual chlorine. There were so many microorganisms in the distribution system that in many sections, especially where the circulation in the mains was poor, the tastes and odors appeared to increase. This, without doubt, was due in part to the fact that in the chloramine treatment we were unable to provide long storage of the water in the distributing reservoirs.

It must be remembered in connection with this work that in the district affected there are about 182 miles of mains in addition to the reservoirs and standpipes in which there are stored, or in circulation, at all times about 55 m.g. of water. It is doubtful if the ammonia-chlorine process was in use long enough to permit all the mains to lose the effects produced by all the organisms, especially by the *Synura* which are much more pungent when dead than when alive.

The three offending organisms present were *Dinobryon*, *Synura* and *Uroglenopsis*. They caused a very fishy taste and odor. When found in a reservoir in warm weather all of these organisms would be expected to dis-

appear in seven to fourteen days, but *Synura* and *Uroglenopsis* prefer colder temperatures and have been known to develop in water under the ice. *Synura*, the most objectionable organism on account of its cucumber

TABLE 2. — AMMONIA-CHLORINE TREATMENT OF SPOT POND WATER FOR CONSUMPTION IN NORTHERN HIGH-SERVICE DISTRICT.

C. H. REED, CHEMIST.

Date, March 1932.	Mil. Gal. Treated.	Chlorine. Lb. per m.g.	Ammonia. Lb. per m.g.	Residual Chlorine at Pumping Station. p.p.m.
3	11.82	...	...	....
4	10.81	4.2	1.1	0.26
5	10.69	4.7	1.2	0.33
6	10.96	4.4	1.0	....
7	10.45	8.6	1.6	0.75
8	10.90	6.6	1.7	0.75
9	11.13	6.3	1.9	0.70
10	10.70	7.0	2.0	0.70
11	11.11	6.9	2.0	0.70
12	10.97	6.7	1.7	....
13	11.14	6.4	1.7	....
14	11.83	6.0	1.8	0.70
15	10.99	7.1	1.8	0.70
16	11.43	7.1	1.8	0.70
17	10.78	7.0	2.0	0.70
18	10.39	7.5	1.9	0.70
19	10.84	8.5	1.7	....
20	11.07	8.3	1.6	....
21	11.03	9.1	1.8	0.70
22	10.45	9.2	1.9	0.70
23	11.00	8.5	1.8	0.75
24	10.79	9.1	1.9	0.75
25	10.50	9.4	1.9	....
26	10.50	9.4	1.9	....

and bitter taste, may cause complaints from consumers who are highly sensitive to odors even before their presence is noted microscopically.

On March 25 it was noted that the taste and odor of the water in the local distribution systems had improved considerably. In some localities there was a faint taste, while in others there still remained a distinct taste with a tendency towards a decided taste on dead ends.

Copper Sulphate Treatment. The ice began to go out of Spot Pond on March 25, and on March 27 the pond was sufficiently clear to warrant copper sulphate treatment. This was carried out under the direction of C. H. Reed, chemist. The copper sulphate crystals were dissolved by dragging through the water 50-pound onion sacks attached to a chute on each

TABLE 3. — AMMONIA-CHLORINE TREATMENT OF SPOT POND WATER RESIDUAL CHLORINE (P.P.M.) IN THE DISTRIBUTION SYSTEM.
C. H. REED, CHEMIST.

Date, March, 1932.	Pumping Station.	Fells Reservoir.		District Supplied.								
		Influent.	Effluent.	Melrose.	Stoneham.	Medford.	Somerville.	Chelsea.	Revere.	Winthrop.	Nahant.	Swampscott
4	0.26	....	....	....	....	....	....	....	....	....	....	....
5	0.33	0.22	0.33	0.10	....	0.20	....	....	....	....	....	....
7	0.75	0.55	....	0.35	....	....	....	....	....	....	....	....
8*	0.75	0.60	....	....	....	0.40	....	....	....	....	....	....
9	0.70	0.55	0.06	....	....	....	....	....	....	....	....	....
10	0.70	0.50	0.07	0.28	Trace	0.15	....	....	....	....	....	....
11	0.70	0.60	0.25	0.25	None	0.15	....	....	....	....	....	....
14	0.70	0.60	0.30	0.35	....	0.20	....	....	....	....	....	....
15	0.70	0.60	0.35	....	....	....	....	....	....	....	....	....
16	0.70	0.60	0.30	0.30	0.25	0.25	0.20	....	None	....	....	....
17	0.70	0.60	0.30	....	....	....	....	....	....	....	....	....
18	0.70	0.60	0.30	0.30	....	....	....	....	....	....	....	....
21	0.70	0.65	0.30	....	....	....	....	....	....	....	....	....
22	0.70	0.65	0.40	0.35	0.05	0.30	....	....	....	....	....	....
23	0.75	0.70	0.40	....	....	....	....	....	....	....	....	....
24	0.75	0.70	0.40	....	....	....	....	....	....	....	....	....
25	0.70	0.70	0.40	....	....	0.30	0.30	0.25	0.15	0.20	None	0.15

*Gates were changed in Fells Reservoir Gatehouse to increase the detention time of the treated water in the reservoir.

side of a motor boat, the boat travelling a zigzag course at a speed of 5 to 15 miles per hour. The chutes facilitated placing the crystals into the bags as needed from the supply in the boat. The size of the crystals was between ½ and 1 in. On March 28, the work was continued, but on March 29, the water was too rough to handle the boat with safety, and the work was finished on March 30, except for one cove which was treated on April 1 after it had lost its ice cover.

A total of 4 700 lb. of copper sulphate was dissolved in the 1 800 m.g. of water, averaging about 2.6 lb. per m.g.

The weather and ice conditions were such as to cause the work to extend over a much longer period than is desirable in treating reservoirs with copper sulphate, but the results proved very satisfactory. During treatment the boat was kept at some distance from the outlet of the reservoir so that the treated water would not be delivered at once to the consumer. High winds on the second and third days after beginning treatment churned the water to a considerable depth and gave off a fishy odor. This showed that the copper sulphate was destroying the *Uroglenopsis* in the reservoir.

Ammonia-chlorine treatment was continued until April 5 and chlorination has been carried on since at a rate of about 3 lb. per m.g. to destroy bacteria.

The information in Table 4, showing the number of microscopic organisms in the waters of Spot Pond for March 4 and 24 and for April 13, was furnished by the State Department of Health.

The complaints relative to tastes and odors of the water began to decline about one week after the reservoir was treated with copper sulphate, and thenceforth the press no longer considered the subject as news. Local authorities were advised to flush the mains wherever complaints were received from consumers.

Resort to Unsafe Supplies. The various sources of water which are drawn upon during troublesome periods such as the one through which we passed must be given thoughtful consideration by all water officials who may be confronted with similar conditions. Private springs, wells and streams were resorted to without any consideration as to the fitness of the water for domestic consumption. The State Department of Health of Massachusetts investigated as far as possible all such sources which were used temporarily during this period, and some of these sources were found to be polluted.

Handling Complaints. There are many people who take no stock in bacteria as they are too small to be seen with the unaided eye and a high-powered microscope is not generally available; but when it comes to tastes and odors produced by microscopic organisms the layman needs no microscope to decide to his own satisfaction that the drinking water is harmful, unsafe and injurious to health. While odors and tastes persisted in Spot Pond water many people were willing to blame all of their ills on the water

TABLE 4. — MICROSCOPIC ORGANISMS IN WATER FROM SPOT POND.

Organisms.	NUMBER OF ORGANISMS PER CUBIC CENTIMETER.							
	MARCH 4.		MARCH 24.			APRIL 13.		
	Raw Water Gatehouse.	Tap in Pump. Sta.	Raw Water Gatehouse.	Tap in Pump. Sta.	Tap in Somerville.	Raw Water Gatehouse.	Tap in Pump. Sta.	Tap in Somerville.
ALGÆ.								
DIATOMACEÆ								
Asterionella	1 468	650	772	654	728	174	132	180
Cyclotella	18	18	10	24	12	6	6	4
Melosira	..	20	..	..	..	8	..	..
Navicula	..	..	..	4	..	..	..	..
Stephanodiscus	..	..	2	..	..	..	..	..
Synedra	8	..	14	10	10	26	38	22
Tabellaria	76	32	52	36	8	2	2	6
CYANOPHYCEÆ.								
Anabæna	2	..	..	..	..	..	..	..
Chroöcoccus	..	16	4	4	8	..	12	..
Microcystis	..	..	2	2	..	..	..	..
Oscillatoria	..	..	..	..	..	..	..	2
CHLOROPHYCEÆ.								
Ankistrodesmus	..	4	4	..	8	..	..	..
Staurastrum	..	..	..	2	..	2	..	..
PROTOZOA.								
RHIZOPODA.								
Amœba	..	..	..	..	..	2	..	..
Arcella	4	..	..	..	..	..	..	..
MASTIGOPHORA.								
Chlamydomonas	2	..	6	..	2	2	4	4
Dinobryon	340	160	390	298	300	132	134	116
Glenodinium	2	..	..	..	..	2	..	..
Monas	..	160	..	840	1 012	32	16	14
Peridinium	2	2	..	..	..	..	..	..
Synura	6	..	4	..	..	..	..	..
Uroglenopsis	38	..	32	..	..	..	..	..
INFUSORIA.								
Vorticella	56	..	20	..	..	6	..	..
ROTIFERÆA.								
Anuræa	2	2	..	..	..	..	..	..
TOTAL ORGANISMS	2 024	1 064	1 312	1 874	2 088	394	344	348

Ammonia-Chlorine Treatment Started March 3, 1932.
Copper Sulphate Treatment Started March 27, 1932.

supply. The different complaints could be classified as justifiable, imaginary or artful, but all complaints, however unjust or imaginary, were investigated promptly and thoroughly. A courteous, frank and sincere talk with the consumer did not always satisfy him, but it did impress him that an interest was being taken in his complaint and that an attempt was being made to remedy the taste. It was a man's job to handle the many calls from consumers and required the patience and forbearance of Job.

In the past the medical profession of Massachusetts has been inclined to be against the treatment of public water supplies with copper sulphate, but of late, after careful consideration, this objection to chemicals has nearly disappeared, providing treatment is supervised by specialists.

Acknowledgments. The writer takes this opportunity to express his gratitude for the valuable information and coöperation he received from Arthur D. Weston, Chief Engineer of the Massachusetts Department of Public Health.

All work connected with the treatment of Spot Pond water was carried on under the immediate direction and personal supervision of William E. Foss, Director and Chief Engineer of the Water Division, and authorized by Davis B. Keniston, Commissioner, Metropolitan District Commission.

Discussion.

Joseph C. Knox.* I shall endeavor to point out certain dangers to public health which resulted when the use of water from Spot Pond was abandoned by consumers because it was unpalatable.

When the tastes and odors first made themselves manifest the public abandoned the safe public water supply and tried to procure a more palatable water from neighboring springs and wells without giving consideration to the purity of these supplies. The demands upon these springs and wells reached enormous proportions as is to be expected when one considers that 192 000 persons were supplied from Spot Pond Reservoir.

The most popular source of supply was Crystal Spring, so-called, located in the Middlesex Fells Reservation near Spot Pond. The demand for water from this source was so great that it became necessary for the Metropolitan District Commission to provide additional facilities for the collection of water. It has been estimated that some 2 000 persons procured water daily from Crystal Spring.

An examination of local springs and wells by the Massachusetts State Department of Public Health, during this emergency, showed that many were unsafe sources of supply. Some springs and wells were located in populated districts where sewage was disposed of through septic tanks in the adjacent ground; others were not adequately protected from the entrance of surface drainage and foreign matter, and at one spring human feces were found deposited on the floor of the spring house. In all, some 15 supplies were examined by the department upon request of the local health

*Massachusetts Department of Public Health, Boston, Mass.

authorities. Of these supplies 10 were found to be unsafe for domestic use.

Added dangers to the health of the community were the use of containers and receptacles of every shape and condition for collecting and transporting water from local sources and the purchase of bottled water of questionable quality. A dangerous practice which was stopped immediately when called to the attention of health authorities was that of supplying patients in a certain hospital with water from questionable sources by friends and relatives.

Considering hazards to the public health such as these, episodes of this kind should serve as a challenge to water-supply officials to control the factors governing the palatability of their supplies so that there will be no need for consumers to abandon even temporarily the public supplies which were instituted for their safety.

When the press published the statement that the water of Spot Pond was to be treated with copper sulphate, the public became alarmed through rumors of the danger of copper poisoning. The dosage of copper sulphate applied to the pond amounted to only 0.310 p.p.m. with a theoretical metallic copper content of .080 p.p.m., while the presence of less than 1.4 p.p.m. of metallic copper in water has not been known to be injurious to health.

Samples to determine the amount of copper present were collected at the gatehouse both before and following the treatment. For each determination a five-gallon carboy of water was distilled. Previous to treatment, the water showed a copper content of 0.009 p.p.m., and the maximum amount of copper was 0.071 p.p.m. four days after the pond had been treated.

Recently Middle Reservoir, one of three reservoirs in the water supply of the town of Winchester, was treated with copper sulphate for the removal of microscopic organisms. Middle Reservoir could be shut off from the system during treatment, while at Spot Pond Reservoir it was necessary to pump water continuously. Conditions at Middle Reservoir were, therefore, considered ideal for carrying on a more intensive study to determine the amounts of metallic copper present in the water as the result of copper sulphate treatment. While these studies have not, at this date, been completed and are not ready for presentation, there is certain information which may be of interest. All samples taken from Middle Reservoir for microscopical examination were composite samples collected from six points in the reservoir. The total number of microscopic organisms per cubic centimeter before treatment was 1 154 of which 390 were *Dinobryon*. With a rate of dosage of 0.17 p.p.m. of copper sulphate there was a reduction in the total number of organisms, one day after treatment, to 680 and of *Dinobryon* to 34. Four days after treatment the total number of organisms was further reduced to 377, and *Dinobryon* was completely removed. The determinations of metallic copper showed 0.017 p.p.m. present before treatment, 0.046 p.p.m. one day after treatment and 0.037 p.p.m. four days after treatment.

THE NASHUA FIRE OF MAY 4, 1930.

BY HON. WILLIAM F. SULLIVAN.*

APPENDIX.†

To better visualize the extent and fierceness of the Nashua fire, the following map, charts and photographs are reproduced. The rôle played

FIG. 1. — THE WEATHER-BEATEN WOODEN LATTICED RAILROAD BRIDGE WHERE THE FIRE STARTED.

Approximately 300 ft. long, sheathed on the top and sides, this bridge was essentially a long wooden tunnel, open at the bottom, making it impossible to strike the heart of the fire with hose streams.

FIG. 2. — BUILDING AT CORNER OF TEMPLE AND SOUTH STREETS.

This was one of the first buildings to be fired by the flying brands and was partially saved, the fire being confined to the roof.

*Mayor of Nashua and President of Pennichuck Water Works.
†For main paper see this JOURNAL Vol. 46, No. 2, June, 1932, p. 204.

by the Wafer Works in providing an adequate supply of water for fire-fighting purposes is shown by charts of water pressure, water consumption and water level in the distribution reservoir. A brief description is added to the caption of each figure.

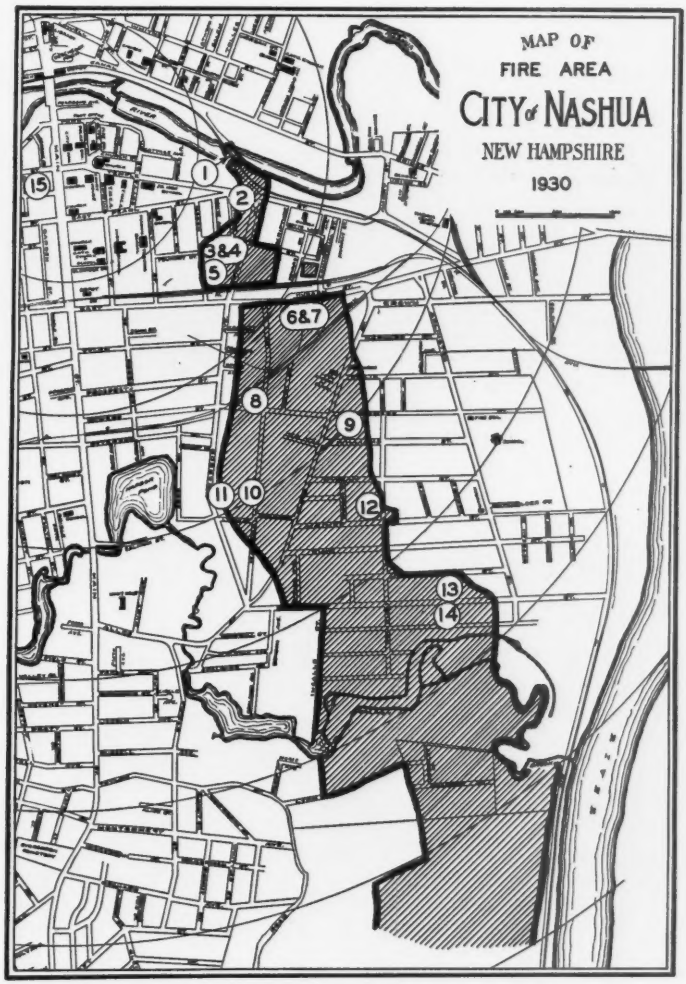

FIG. A. — MAP OF FIRE AREA.

This map shows the location of the area with respect to the rest of the city, and the Pennichuck Water Works Office (15) where a recording pressure gage is located. The numbers in circles indicate the place at which the pictures shown in this appendix were taken.

FIG. 3. — BUILDINGS AT CORNER OF WHITE AVENUE AND WORCESTER STREET.
These two and three story frame dwellings were situated about one thousand feet from the starting point of the fire.

FIG. 4. — BUILDINGS AT CORNER OF WHITE AVENUE AND WORCESTER STREET.

FIG. 5. — CHECKING THE FIRE ON MASON STREET.

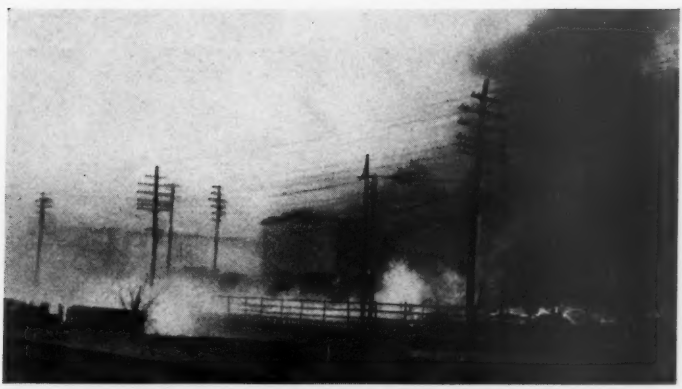

FIG. 6. — WHITE MOUNTAIN FREEZER CO. AND PROCTOR BROS. COOPER SHOP IN FLAMES.

Note the flaming pile of staves and lumber. The intense heat and wind carried flaming brands several miles.

FIG. 7. — WHITE MOUNTAIN FREEZER CO. AND PROCTOR BROS. PLANTS.

These buildings were supplied with water through one 8 in., one 6 in., one 2 in., and several smaller pipes. When the buildings had burnt down, these broken services were a heavy drain on the system.

FIG. 8. — FIRE ON BOWERS STREET.

Note the abandoned hose and hydrant in the foreground.

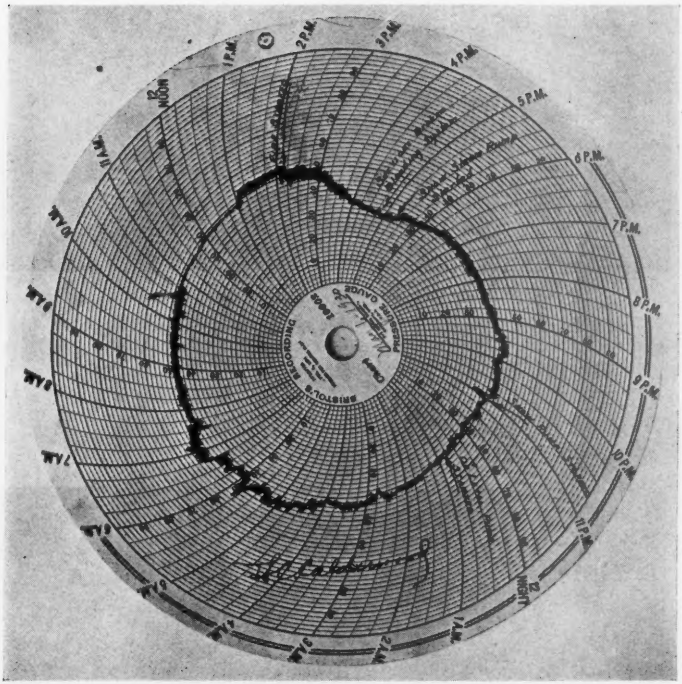

FIG. B. — CHART FROM RECORDING PRESSURE GAGE, LOCATED AT THE OFFICE OF THE PENNICHUCK WATER WORKS AT 11 HIGH STREET.

This chart recorded the pressure throughout the fire period and shows the effect of broken services, abandoned hydrants, and hose streams. At no time during the fire did the pressure drop below thirty-two pounds per square inch at the office.

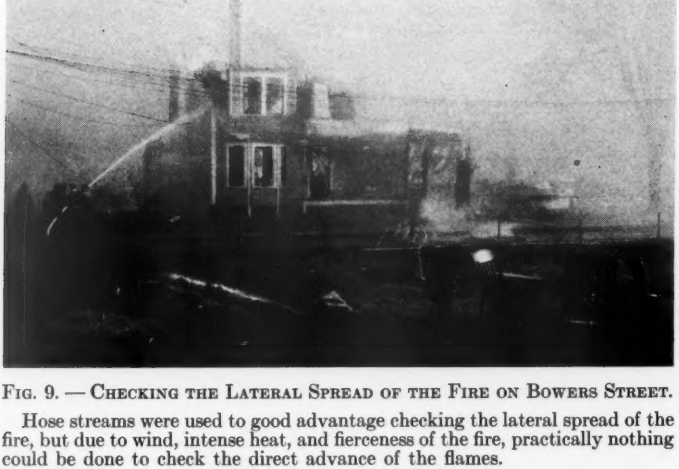

FIG. 9. — CHECKING THE LATERAL SPREAD OF THE FIRE ON BOWERS STREET.

Hose streams were used to good advantage checking the lateral spread of the fire, but due to wind, intense heat, and fierceness of the fire, practically nothing could be done to check the direct advance of the flames.
(*Photo by Sunset Studio.*)

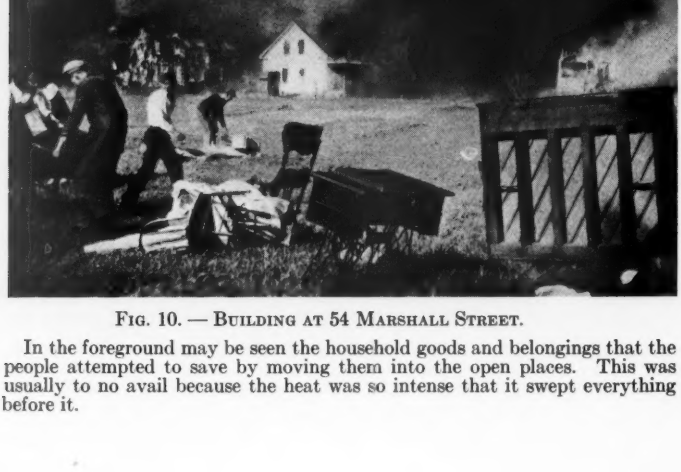

FIG. 10. — BUILDING AT 54 MARSHALL STREET.

In the foreground may be seen the household goods and belongings that the people attempted to save by moving them into the open places. This was usually to no avail because the heat was so intense that it swept everything before it.

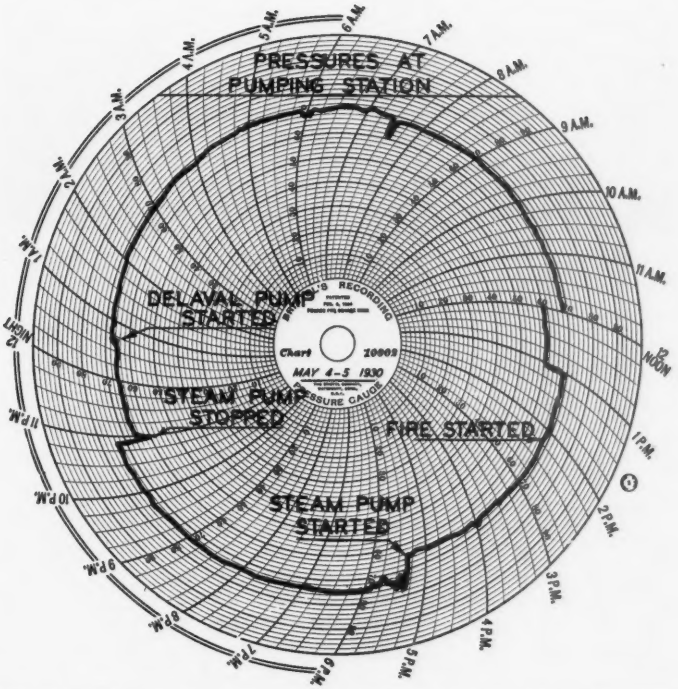

FIG. C. — CHART OF RECORDING PRESSURE GAGE LOCATED AT THE PUMPING STATION.

This chart shows that in spite of the huge draft, the pressure was maintained above normal throughout the fire.

FIG. 11. — VIEW OF PROCTOR BROS. LUMBER YARD FROM HARBOR AVENUE. This is only one of the many lumber yards that were swept absolutely clean.

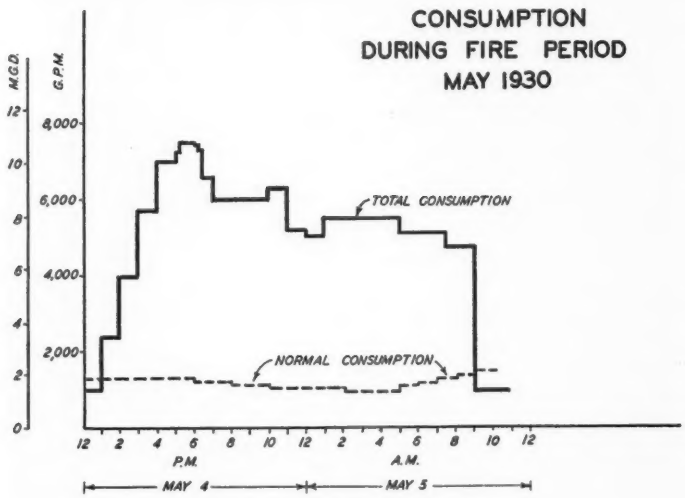

FIG. D. — CONSUMPTION CHART.

This chart permits comparing the normal Sunday consumption with the draft due to the demand of the fire engines, broken and bleeding services, abandoned hydrants and hose streams, and hundreds of garden hoses being used to wet down roofs and other property.

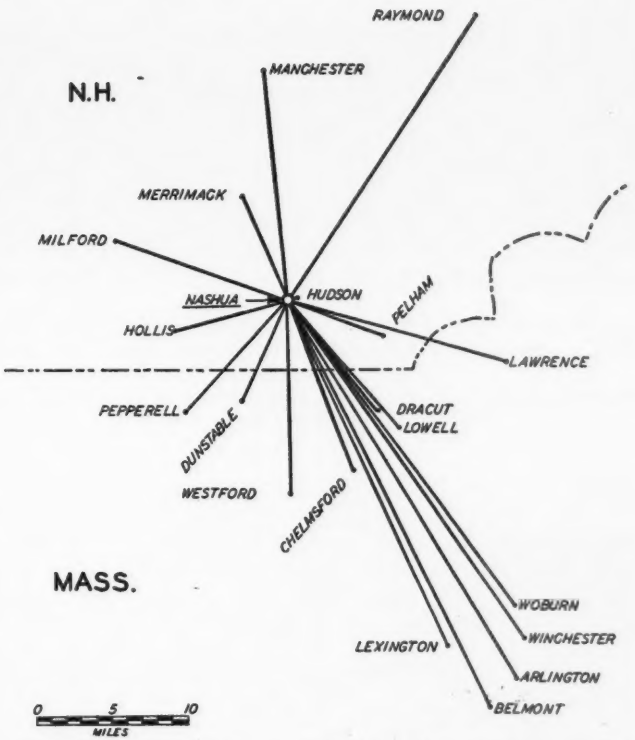

FIG. E. — TOWNS AND CITIES WHICH SENT AID TO NASHUA DURING THE FIRE.
See Table 1, page 207 of the June 1932 JOURNAL for the complete record.

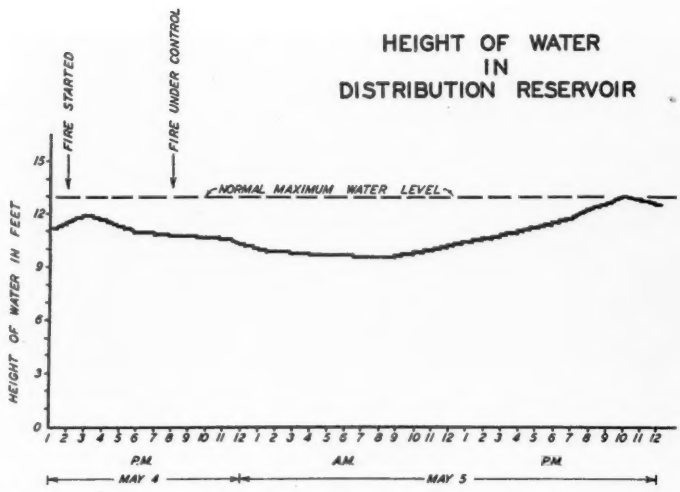

FIG. F. — RECORD OF HEIGHT OF WATER IN THE 4-M.G. DISTRIBUTION RESERVOIR.

This chart shows that in spite of the heavy draft the water level dropped only 0.8 ft. during the first six hours of the fire.

FIG. 12.—BURNING BUILDINGS ON NEWBURY STREET, NASHUA, N. H.

FIG. 13. — LUMBER YARD AND DWELLINGS ON BURKE STREET BEING CONSUMED BY THE FLAMES.

This section was fired by the flaming brands, before many places much nearer the start of the fire were ignited.

(*Photo by Sunset Studio.*)

FIG. 14. — BURKE STREET LUMBER YARD OF THE AMERICAN BOX & LUMBER CO. ACTUALLY A GIGANTIC ROARING FURNACE.

The fire was so intense and the wind so strong that everything was swept clean, hardly a piece of charcoal remaining of what was once a huge pile of lumber. This firm alone lost over ten million feet of lumber on the "sticks."

(*Photo by Sunset Studio.*)

USE OF WATER IN GAS-OPERATED REFRIGERATORS.

(Superintendents' Discussion, December 9, 1931.)

DAVID A. HEFFERNAN.* Water departments at present are looking into the loss of revenue on water used, but not registered, by gas-operated refrigerators. Tests made in different localities indicate that the amount of water consumed by this type of refrigerator unit, but not registered by the water meter, varies in amount, sometimes reaching 75 per cent. of the water consumed by the unit. It is my understanding that a box of 7-cu. ft. capacity uses approximately 10 cu. ft. of water daily. In a year this would amount to about 3 600 cu. ft.; tests made in New York City by the water department showed a range from about 2 500 to 12 000 cu. ft. annually. As a result of such tests, New York, Chicago and St. Louis make a flat annual water charge of $2.50 for gas-operated refrigerators.

A number of conditions affect the consumption of water. Among them are: size of the box; adjustment of the needle valve controlling the water supply; temperature of the room in which the unit is placed; temperature of the water delivered to the box; and adjustment of the gas flame.

Proper adjustment of the water supply normally permits a continuous drip of water except when the box temperature rises due to repeated opening of the doors or the placing of hot food in the box. At such times a greater supply of water is passed automatically through the refrigerator. This water, in my judgment, is sufficient to be registered accurately on ordinary water meters. It is the normal low consumption with which we are most concerned.

I do not favor the flat charge because it does not take into consideration the variation in water consumption or other local conditions. One suggestion that has been made to solve the problem is that a small super-sensitive meter be placed in the supply to the refrigerator. It seems to me that one meter supplying all the fixtures in the house is more practical. I feel certain that the water used by a gas refrigerator, when added to the water wasted through dripping faucets or other defective plumbing fixtures, will register on a sensitive meter such as we are able to obtain today. Possibly in the not too distant future meters will be so improved that much of the water now used, but not registered, will be recorded by the ordinary water meter.

There is one method that would make certain that water consumed by a refrigerator would be registered. According to it a tank similar in size and operation to a flush tank supplying a toilet would be placed above the refrigerator. The tank could be equipped with a ball valve which would open when the tank was nearly empty and stay open until it filled, thus permit-

*Superintendent of Water Works, Milton, Mass.

ting a rate of flow of water into the tank sufficiently great to register on a meter. The supply to the refrigerator would be tapped into this tank and would permit gravity flow as required by the refrigeration unit. Such equipment could be required through local ordinance or water department regulation.

PERCY R. SANDERS.* As recently as the first of this month one of our consumers complained about the size of his bill expressing himself as unable to see how he could use so much water as he had no leaky fixtures; but he did have a gas refrigerator. Our men investigated and found his fixtures tight but the meter travelling at the rate of about a 0.1 cu. ft. in 10 minutes, 14.4 cu. ft. in 24 hours, or 1 300 cu. ft. per quarter, costing $1.95. The consumer requested a test on the meter, but before we were able to comply the gas company changed the water control on the refrigerator, cutting the consumption to 0.1 cu. ft. in 35 minutes reducing the cost of water to approximately $0.60 per quarter.

Another consumer who has a gas refrigerator uses 0.1 cu. ft. in 14 minutes or 800 cu. ft. per quarter amounting to a water bill of $1.20.

A test made by running the effluent water from an ordinary household type of refrigerator into a barrel and measuring carefully the amount of water collected showed that 60 gallons were used in 24 hours, approximately 700 cu. ft. per quarter at a cost of $1.05. The temperature of the outgoing water was 90° F.

About thirty of these refrigerators are used in Concord. In most cases the excess cost of water used does not cause the consumer any undue alarm. The control which cut the cost from $1.95 to $0.60 was one of the latest types, the others being of an older style. Variations may, therefore, be accounted for by differences in type of control, in temperature of outgoing water (varying from 90° to 100° F.) and in amount of refrigeration required.

HERBERT C. CROWELL.† When the first gas refrigerators were installed in Haverhill, the consumers' water bills became greater, and a number of people came into the office to complain about the increased use of water and were surprised when informed that their gas refrigerators were responsible. In this connection it must be remembered that the old type of refrigerator used considerably more water than the new type.

Since the gas company took exception to our statement that the refrigerators were to blame for the extra water used we installed meters on the pipe lines feeding refrigerators in different houses of the city. We found in most cases that the amount of water registered by the meter was very small and came to the decision that the meters were not recording all of the water passing through. A record of water used in houses equipped with gas refrigerators during 1928 and 1929 is given in the accompanying table. Following this are the results of 24-hour tests made for the Boston Consolidated Gas Company at the Massachusetts Institute of Technology on a gas-operated refrigerator.

*Superintendent of Water Works, Concord, N. H.
†Superintendent of Water Works, Haverhill, Mass.

WATER CONSUMED IN HOUSES EQUIPPED WITH GAS REFRIGERATORS DURING 1928 AND 1929. HAVERHILL, MASS.

ANNUAL CONSUMPTION IN CUBIC FEET.

Date of Installation.	Year. 1927.	1928.	1929.	1930.
1928: 3–24	14 830	18 720	24 620	17 940
4–21	4 020	6 850	11 970	13 460
4–30	3 480	11 640	13 510	6 420
5–10	10 740	21 090	22 980	15 910
6– 1	——	7 510	18 250	19 980
6– 4	3 770	5 870	11 750	17 730
6–29	5 200	12 130	16 780	13 920
7–12	——	20 980	22 780	22 490
8– 2	1 430	2 570	1 730	3 250
10–25	2 270	4 440	7 740	9 960
12–21	7 950	7 120	11 460	9 410
1929: 1– 2	5 290	6 340	8 420	10 700
3– 9	2 220	3 850	6 860	11 340
3–28	5 740	6 060	3 240	17 030
4– 1	3 820	4 730	10 130	7 580
4–15	8 700	10 410	14 370	20 090
4–23	5 330	4 460	17 650	21 110
6–11	12 730	6 890	8 630	17 660
6–15	5 190	5 710	10 650	16 480
6–18	25 020	35 180	44 690	38 100
6–29	11 830	15 140	16 810	18 100
7–19	5 210	4 260	3 440	10 240
8–12	6 020	8 960	9 910	10 110
8–30	17 260	18 570	18 010	17 050
9– 6	26 400	14 810	12 100	18 860
10–16	8 940	8 930	13 890	13 850
10–16	5 800	11 630	16 900	12 020
10–31	9 210	6 850	11 970	13 460
12– 5	6 630	7 740	9 830	16 950
12–17	9 170	11 850	26 230	12 100
12–30	12 640	11 410	22 660	21 580

USE OF WATER BY GAS-OPERATED REFRIGERATORS UNDER SUMMER AND WINTER CONDITIONS.

Water Used.	Water Temperature. 68–70 F.	40–45 F.
Gallons per hour	4.75	2.14
Cubic feet per hour	0.632	0.284
Cubic feet per day	15.2	6.8
Cubic feet per month	455	204

It will be noted that the amount of water used under winter conditions (40–45° F.) was 204 cu. ft. per month, whereas the volume recorded for summer conditions was 455 cu. ft. per month, or more than twice as much.

The water passing through the refrigerator is used for cooling and condensing purposes. The valve that regulates the flow of water into the refrigerator is called a siphon valve, or Fulton control. When the waste water falls below a temperature of 90° F. the valve closes and the flow of water is checked, but as the valve does not close tightly there is always a small flow through it. When the temperature of the water rises above 90° F. the valve

opens and admits more water for cooling purposes. The valve, therefore, is in constant operation. It is the water that is flowing through when the valve is supposed to be closed which, in my opinion, is not registered by the meter.

At Haverhill, the gas company reads the water meter at the same time as the gas meter, where a gas refrigerator is installed. If a large run is recorded on the water meter, the inspector immediately checks up on the adjustment of the siphon valve and regulates it to a lower flow.

JAMES J. FITZGERALD.* As a result of many complaints from users of gas-operated refrigerators and after several conferences with the Springfield Gas Light Company, we decided to run a test at my home on the amount of water used by a gas-operated refrigerator. We had four meters in operation. Two of them were on the entire use of the house, and two of them on the refrigerator line. The latter were set on a $\frac{5}{8}$ in. brass pipe branched from the main supply just inside the house meters, so that they received the full pressure of the service supply, about 70 lb. per sq. in. The brass pipe was carried the full length of the cellar, about 40 ft., to the refrigerator tubing, the pressure being cut down to 15 lb. per sq. in. after passing through the reducing valve at the tubing.

The meters on the refrigerator line recorded the following amounts of water:

Date.	Registration in Gallons. $\frac{3}{4}$-in. Meter.	$\frac{1}{2}$-in. Meter.	Percentage Ratio of $\frac{1}{2}$-in. registration to $\frac{3}{4}$-in. registration.
Jun. 16–Jul. 5	1 898	539	28.4
Jul. 5–Jul. 31	2 906	1 571	54.1
Jul. 31–Aug. 31	3 674	2 483*	67.6
Aug. 31–Sep. 30	2 755	1 287	46.7
Sep. 30–Oct. 31	1 793	1 346	75.2
Oct. 31–Nov. 30	1 622	1 174	72.4

*Registered by a different $\frac{1}{2}$-in. meter.
NOTE. The $\frac{3}{4}$-in. meter was new, the $\frac{1}{2}$-in. meter old.

From these results we concluded (1) that a $\frac{5}{8}$-in. meter that had been in service for some time would register from 60 to 75 per cent. of the water used by a gas-operated refrigerator; (2) that this amount would be augmented by small leaks or low flows that of themselves would not be registered; and (3) that the loss to the water-works department, if any, would be small.

Before closing I want to cite a case which will serve to illustrate our difficulties in trying to explain the increase in water bills due to the use of gas-operated refrigerators. On one of our streets there are two cottages, about 50 feet apart. Each has a gas-operated refrigerator. In one cottage the increase in the use of water is scarcely noticed on the quarterly bill. It is not over a dollar. In the other house the increase in the bill is about $3 a quarter. I believe the answer to this difference is as follows: in one house a

*Chief Inspector, Springfield, Mass.

combination of a very slow flow of water through the refrigerator and a sluggish meter gives a low registration; while in the other house there is a larger flow through the refrigerator and a more sensitive meter.

JAMES W. GRAHAM.* For the benefit of those who represent water works which are not entirely metered, I wish to say that at Portland where we are about 50 per cent. metered, we began with the idea of installing a meter on previously unmetered premises whenever a gas refrigerator was installed. We found, however, that this was working a hardship on the gas company, inasmuch as there was severe competition between gas and electric refrigeration. After carrying on some tests on the amount of water consumed by gas refrigerators, our trustees, therefore, filed a flat rate for unmetered premises. This rate reads as follows: "Gas refrigerators of the absorption type, covering boxes up to and including 5 inside cubic feet capacity, $5 per year. An extra charge of 50 cents per annum shall be made for each additional cubic foot inside capacity up to and including 10 cubic feet capacity. For boxes over 10 inside cubic feet capacity the rate shall be determined by meter." That rate was satisfactory to the gas company.

S. ALFRED BENSON.† At Arlington, the gas company has coöperated with us by installing regulating valves to keep the use of water down to a minimum.

GEORGE P. LANGTON.‡ On installations which have been made in our territory we have used a water-pressure regulator in every instance. This regulator is set at a maximum of 15 lb. per sq. in. We found that this valve stopped complaints and made it easier for us to adjust our water valves on the boxes.

*General Manager, Portland Water District, Portland, Me.
†Water Registrar, Arlington, Mass.
‡Of the Arlington Gas Company.

DIFFICULTIES WITH WATER BILL COLLECTIONS DURING THE DEPRESSION.

(Superintendendents' Discussion, May 11, 1932.)

ROGER W. ESTY.* For the last three or four months there have been, at Danvers, customers who have run up bills of $10 to $20, that may have extended back for a year. Let me cite how we have handled some of these bills.

If a person has owed $8, he has been allowed to work out his debt if he wanted to. We have done reforestation, which has provided a considerable amount of work. We have paid 50 cents an hour, $4 a day, for such work, giving two days work to pay the water bill and an additional two days to provide a little money besides. Sixty persons have availed themselves of this opportunity which clears the accounts and balances our books. Everybody to whom we have made the suggestion that he work out his bill, has been glad of the opportunity. We are planning to start some pipe laying and have a number of men on the waiting list who want an opportunity to work out their bills on this job.

We applied a lien on 15 or 20 properties a year ago; some $334 or $340 were involved. All bills were paid except $30. If the accounts that run back into last year are not paid by August 15 of this year, we shall enforce the lien law. The amount outstanding will be included in the tax bill when it is sent out on September 1.

PERCY R. SANDERS.† We have been agreeably surprised in Concord at the rate at which collections have come in. Our bills are levied against the owner of the property. If the tenant wants to pay, he has that privilege, but the bill is made out to the owner. We have had to do a lot of hammering to collect some of our bills and have had to let some of them be paid on the installment plan. Some men we have allowed to work out the bill, giving them a week's work cutting brush around the pine trees on the water sheds.

We had no lien law in New Hampshire until 1927, when a law was passed making the water bill a lien on the real estate if in force a year from the date of the last bill. I have had to use this law in two cases during the last quarter. Two firms went into bankruptcy, and I received notice from them requesting that we join the creditors and take our assessment with them. We wrote back that the water bill was a lien on the property just the same as the tax bill. Both of those bills have been paid in full.

We had to shut off two services last year, and there remain two uncollected bills.

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*Superintendent of Water Works, Danvers, Mass.
†Superintendent of Water Works, Concord, N. H.

ALBERT L. SAWYER.* I was glad to see this subject on the program for I was of the opinion that I was the only one who was having any trouble in collecting bills. We have had our share of the depression in Haverhill, and at the present time we are collecting our bills the best we can. A good many people pay a dollar a week or two dollars a week.

To show how things have gone: at the end of the year 1926 we had no unpaid bills; in 1927, $39.94; in 1928, $149.15; in 1929, $445.07; in 1930, $1 405.86; in 1931, $2 071.69.

On January 31, 1927 we had unpaid water bills to the amount of $5 287; in 1928, $6 686; in 1929, $7 257; in 1930, $10 096; in 1931, $17 921.

When people are disposed to pay we try to get along without shutting off the service. A great many people who own tenements are not getting their rent. I know of a man with a number of tenements who has unpaid rent bills amounting to $2 000.

This year a shoe manufacturing concern was not able to pay its water bill. It has not paid it yet. About the only thing we can do is to take what we can get and hope for the best.

LEON A. GOODALE.† I cannot say that we are having much trouble at Worcester. While we are having a great deal of work in collecting water bills, public sentiment up to the present time seems to support the theory that water bills should be paid, and we are proceeding as best we can to collect them.

We are probably employing four times as many shut-offs and four times as many liens as we did two or three years ago, but we have the satisfaction of knowing that we have collected more money in the first five months of this year than we did a year ago.

Mention has been made of the possibility of allowing those who take water, to work out their bills. This can be done where local conditions permit. In Worcester we could not do it. All of our help is employed under Civil Service Rules and Regulations, and we have no authority to permit anyone to work out a water bill unless his name is certified by the Civil Service Commission.

There is one thing I want to speak of in connection with the application of liens that we feel is working out successfully in Worcester. We are in close contact with the banking institutions in the city, and when the time has arrived to apply a lien we get in touch with the bank financially interested and let it know. Usually the bank holding the mortgage sees that the bill is paid,— much to the relief of the water department.

STEPHEN H. TAYLOR.‡ New Bedford, like other cities, has had some trouble in collecting water bills. Our present policy is to allow the consumer to pay on the installment plan, if it is necessary. In cases of distress, we are not shutting off the water for non-payment of bills but are applying a

*Water Registrar, Haverhill, Mass.
†Water Commissioner, Worcester, Mass.
‡Superintendent of Water Works, New Bedford, Mass.

lien if the account remains unpaid for sixty days. We find that this helps the situation somewhat.

We had one case of a manufacturing plant that went into the hands of a receiver who agreed to be responsible for the water bill after the date of receivership, but not before. We did not want, by turning off the water, to shut down any plant that would run and employ help, so we accepted their proposition and put a lien on the property for the part of the water bill contracted before the receivership.

I do not think we have had more than the average amount of trouble in collecting bills. The payments are a little slow, but on the whole collections are fairly good.

PERCY SANDERS. How about old bills that have been uncollectible for four or five years. Are they crossed off the books or abated and charged to loss?

STEPHEN H. TAYLOR. In New Bedford we do not have any bills that old. We either shut the water off or put a lien on the property. Anything that has occurred since the enactment of the lien law is easily collected in that way. Prior to that time if a bill was not collected it would have to be crossed off. With the lien act there is no need for allowing a bill to go that long.

WILLIAM F. SULLIVAN.* Private corporations are no more severe in the matter of collections than are publicly owned water departments. At Nashua, we have a few consumers who cannot pay now and a few more who will never pay because of age, loss of jobs and a complete falling away of future prospects. We do not believe it is the right time, in a few cases, to shut the consumer's water off. In comparison with other lines of business our losses are small.

Municipally owned water works in Massachusetts and New Hampshire have a great advantage over privately owned ones. Both are business enterprises and trading operations. Privately owned companies are taxed and regulated and do not have state laws to help enforce collections. The others, city owned, have the taxpayers' and the rate payers' backing with practically no regulation or accounting control from without, and we find them confronted with a necessity for drastic methods of collections.

The private companies must pay their bills and follow the "golden rule." We truly can say that with the use of the gentle method, our losses from non-payment of water bills are comparatively small.

HENRY T. GIDLEY.† I do not think that our collections at Fairhaven are so bad considering the circumstances. There are many people, however, who are able to pay but play on the depression to avoid doing so. That is the class of people we have had trouble with. The poor fellow who doesn't have any money tells us about it and as soon as he gets a dollar he pays; but many a man who rides around in an automobile says his business is very poor whether it is or not.

*President, Pennichuck Water Works, Nashua, N. H.
†Superintendent, Fairhaven Water Co., Fairhaven, Mass.

A COMPARISON OF METHODS FOR DETERMINING THE AREAL MEAN PRECIPITATION ON DRAINAGE AREAS.

BY JOHN B. BELKNAP.*

[*Received June 1, 1932.*]

The common method of determining mean precipitation on a drainage basin is to take a direct average (arithmetic mean) of the records of rainfall stations lying within the basin. This is the simplest and in many cases the most reasonable thing to do. There are, however, several other methods which may be usefully employed in making this determination, the most logical of which appear to be the Thiessen method and the drawing of isohyetal lines, or lines of equal rainfall.

Robert E. Horton, in a paper which appeared in this JOURNAL,† has discussed the merits of these and other methods and has expressed the opinion that more precise procedure than the taking of the direct average is sometimes warranted. The factors which influence the choice of method are listed by Horton as follows:

1. Size, shape, and topography of the drainage basin.
2. Number and position of the rain gages in relation to the area.
3. Accuracy obtainable and accuracy desired in the result.
4. Labor involved in the reduction of the data.

The present paper gives the results of a comparison of two or more of the methods previously mentioned, applied to each of three well-gaged watersheds in Massachusetts, rainfall figures for 1930 being used. The direct average and the Thiessen method are compared in each instance, and three additional methods are tried for one of the drainage areas. The drawing of isohyetal lines is generally so laborious as to preclude its use except where unusual precision is desired. This leaves the Thiessen method as the only one to compete with the direct average.

Horton, who is responsible for developing Thiessen's procedure on a practical working basis, has demonstrated its use in the paper already referred to. It is based on the principle that "a rainfall record at any station shall be used to represent the precipitation on that portion and only that portion of the drainage basin to which it lies nearer than any other station." The drainage basin is divided into subareas by the simple geometrical process of drawing perpendicular bisectors between adjacent stations on the map. Having bounded these subareas they may be planimetered and the percentage of the total area which each subarea represents can then be used to weight the corresponding rainfall record. This procedure is reasonably

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†JOUR. N.E.W.W.A., 38, 1924, pp. 1–43.

simple and, once ascertained, the weighting of the stations will remain the same so long as there is no change in their number or location. One advantage in this method is that, while it takes account of stations lying outside the watershed, it eliminates automatically any station lying too far distant to be worthy of consideration.

It frequently happens that the engineer whose task it is to utilize rainfall data knows little or nothing concerning them other than the location of the station and the amount of precipitation recorded. He may have no knowledge of the elevation or exposure of the gage, care with which readings were taken, or the accuracy of snow measurements. In that case he must assume that all the records he is using are equally reliable.

Since the geographical position of the stations is known, it seems logical to take it into account in determining areal mean precipitation and to apply the Thiessen principle by weighting the individual rainfall records. If, however, it is found that the results obtained by the use of this method are substantially the same as those given by taking a direct average, the use of the latter and simpler procedure is indicated. The amount of variation in the results obtained by these two methods will depend upon the number and distribution of the rainfall stations used, as well as the actual range in rainfall over any period under consideration. It should be remembered that stations lying adjacent to the watershed will be included in the Thiessen method but generally are not used in finding the direct average.

The purpose of this paper is to determine how great an actual difference results from the use of two or more methods when they are applied to three existing well-gaged Massachusetts drainage basins and whether or not in the examples chosen the Thiessen method shows enough variation over the direct average to warrant its use in view of the additional labor involved.

The three drainage areas selected are those of the Wachusett Reservoir (108.8 sq. mi.), the Charles River at Waltham (158 sq. mi.), and the Chicopee River at Bircham Bend (704 sq. mi.).

Wachusett Catchment Area.

As shown on the accompanying map (Fig. 1), there are four rainfall stations within the Wachusett watershed. Ten additional stations lie outside the drainage area, only one of which is more than three miles from the divide. There is also a rain gage on the summit of Mt. Wachusett, the highest point of the watershed, where records are kept during the summer months.

Using only the four rainfall stations within the drainage area, the monthly and annual mean rainfalls for 1930 have been obtained by employing (1) the direct average, (2) the Thiessen method, (3) the center of gravity method, as summarized in Table 1. In the center of gravity method the observations are weighted inversely as the distances of the stations from the center of gravity of the figure of the drainage area. Table 1 includes

also the results obtained by using, in addition to the four stations within the catchment area, six or more of the adjacent stations, and finding the mean rainfall (4) by isohyetal lines (15 stations used), (5) by the Thiessen method (11 stations used), (6) by the center of gravity method (10 stations

FIG. 1.—RAINFALL STATIONS ON WACHUSETT CATCHMENT AREA.

used), and (7) by arbitrary weighting (data for six outside stations given one-half the weight of the data for the four stations within the divide).

In drawing the isohyetal lines, 15 stations were taken into account, but if, in any month, one station was not in accord with the trend in rainfall, the influence of this station was disregarded. In the Thiessen method, 7 outside stations were assigned subareas totaling 25 per cent. of the drainage area. In methods (6) and (7) only outside stations less than two miles distant from the divide were used. Table 2 shows the weights assigned

TABLE 1.— MONTHLY AND ANNUAL MEAN RAINFALL ON THE WACHUSETT WATERSHED, 1930.

METHOD OF COMPUTATION.	MONTH.												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	YEAR.
Using 4 Stations within the Divide.													
1 Direct Average	2.11	2.20	3.66	1.87	2.77	2.95	5.71	1.69	1.91	3.55	3.92	2.61	34.95
2 Thiessen Method	2.11	2.21	3.65	1.88	2.78	3.02	5.77	1.70	1.95	3.53	3.92	2.60	35.12
3 Center of Gravity Method	2.08	2.16	3.65	1.85	2.73	3.03	5.94	1.68	1.87	3.48	3.94	2.58	34.99
Using 6–11 additional Stations outside the Divide.													
4 Isohyetal Lines (15 sta.)	2.10	2.12	3.64	1.91	2.83	3.02	5.44	1.66	1.92	3.64	3.88	2.44	34.60
5 Thiessen Method (11 sta.)	2.11	2.13	3.63	1.88	2.85	3.10	5.45	1.67	1.85	3.56	3.91	2.53	34.67
6 Center of Gravity Method (10 sta.)	2.10	2.09	3.57	1.89	2.94	3.23	5 41	1.62	1.87	3.63	3.88	2.47	34.70
7 Arbitrary Weighting (10 sta.)	2.11	2.11	3.58	1.89	2.94	3.16	5.34	1.64	1.88	3.64	3.87	2.49	34.65

to each station by the various methods, except by the rainfall-contour method in which weighting is indeterminate.

The results obtained by the seven different methods are in close accord. This is due to the uniformity in the rainfall over the area and to the dominating position occupied by the four stations located within the area. From a study of the results it appears that for practical purposes the direct

TABLE 2. — PERCENTAGE WEIGHT ASSIGNED TO RAINFALL STATIONS ON WACHUSETT WATERSHED IN COMPUTATION OF MEAN RAINFALL.

	METHOD OF COMPUTATION.					
STATION.	1	2	3	5	6	7
Jefferson	25	28.2	22.3	16.0	12.0	14.29
Princeton	25	26.0	27.0	19.1	14.5	14.29
Sterling	25	24.5	34.7	22.2	18.3	14.29
Boylston	25	21.3	16.0	17.6	8.5	14.29
Wachusett Lake	..	....	....	6.9	7.1	7.14
Kendall Reservoir	..	....	....	6.3	10.2	7.14
Winter Hill	..	....	....	5.1	7.4	7.14
North Rutland	..	....	....	3.0	7.3	7.14
Clinton	..	....	....	2.2	7.7	7.14
Holden Reservoir	..	....	....	1.3	7.0	7.14
Leominster	..	....	....	0.3	....	....

average of the four stations within the watershed will yield results sufficiently precise for all general purposes to which information of this kind can be put.

CHARLES RIVER CATCHMENT AREA.

As shown in Fig. 2, the Charles River above the gaging station in Waltham has a natural drainage area of about 250 square miles. Water is diverted from the river at two points, however, so that the effective drainage area is only about 158 square miles. The city of Cambridge takes its principal supply from Stony Brook, one of the tributaries of the Charles, and except at times of high run-off no water reaches the river from 23.6 square miles of watershed. The other diversion is that of one-third of the flow of the Charles at a point in Dedham, into the Neponset River, via Mother Brook, thus reducing the effective catchment area by an additional 66.2 square miles.

In determining the mean precipitation on this watershed, the area was divided into three sections, the area of Stony Brook, which was omitted from consideration, the area above the Mother Brook diversion, and the area below this diversion. Since only two-thirds of the water from the upper area is retained in the river, it is reasonable to take this into account in using the rainfall records gathered on this portion of the watershed. This can readily be done in the Thiessen method by treating the two sections of

TABLE 3.— MONTHLY AND ANNUAL MEAN RAINFALL ON THE CHARLES RIVER WATERSHED, 1910 AND 1930.

METHOD OF COMPUTATION.	MONTH.												YEAR.
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Using 1910 Stations and Rainfall Data.													
1 Thiessen Method (11 stations)	5.44	4.56	1.49	2.52	1.52	4.28	2.04	1.92	2.33	1.54	4.52	2.36	34.52
2 Direct Average (5 stations)	5.35	4.46	1.56	2.47	1.55	4.11	1.99	1.73	2.35	1.50	4.64	2.28	33.99
3 Weighted Average (5 stations)	5.35	4.46	1.50	2.46	1.52	4.19	1.96	1.62	2.39	1.50	4.62	2.27	33.82
Using 1930 Stations and Rainfall Data.													
4 Thiessen Method (13 stations)	2.83	2.37	3.36	2.04	2.77	2.09	3.15	2.33	0.52	4.61	3.94	2.60	32.61
5 Direct Average (8 stations)	2.85	2.34	3.27	2.00	2.80	2.08	3.21	2.31	0.47	4.75	3.92	2.56	32.56
6 Weighted Average (8 stations)	2.84	2.34	3.24	2.02	2.84	2.05	3.27	2.39	0.47	4.86	3.96	2.59	32.87
Using 1910 Stations and 1930 Rainfall Data.													
7 Thiessen Method (11 stations)	3.23	2.52	3.38	2.02	3.06	2.34	2.99	2.24	0.50	4.88	4.12	2.84	34.22
8 Direct Average (5 stations)	3.08	2.44	3.43	2.02	2.89	2.06	3.30	2.42	0.49	4.94	4.11	2.85	34.03
9 Weighted Average (5 stations)	3.03	2.43	3.39	2.04	2.92	2.04	3.34	2.44	0.49	5.01	4.10	2.83	34.06

the drainage area separately and reducing the subareas above the diversion by one-third before determining the percentage of the entire area to be allotted to each rainfall station. Another method tried was to weight the stations below the diversion one-half more than those above.

FIG. 2.—RAINFALL STATIONS ON CHARLES RIVER CATCHMENT AREA.

Estimates of mean rainfall on this watershed have been made for the years 1910 and 1930 by three methods. In addition the mean precipitation was found for 1930 using only the records of stations which were available in 1910. Both 1910 and 1930 were years of low rainfall in eastern Massachusetts, averaging less than 35 in. In 1910 the only rainfall stations on the watershed were at Newton Pumping Station, Stony Brook Dam, Waltham

Pumping Station, and Moody Street, Waltham. All of these stations lie on the lower part of the watershed, and the latter three are so close to one another as to represent the rainfall on a very limited area. To estimate the rainfall on the main portion of the watershed it was necessary to use a number of stations lying in adjacent drainage areas, particularly Diamond Hill (R.I.), Ashland Reservoir, and East Walpole. Between 1910 and 1930, four rain gages were established within the catchment area, and another was added near the divide, so that more reliable estimates can be expected

TABLE 4. — PERCENTAGE WEIGHT ASSIGNED TO RAINFALL STATIONS ON THE CHARLES RIVER WATERSHED IN COMPUTATION OF MEAN RAINFALL.

STATION.	METHOD OF COMPUTATION.					
	1	2	3	4	5	6
Diamond Hill (R. I.)	12.2	20	16.7	....	....	..
Woonsocket (R. I.)	4.2	..	....	....	....	..
Northbridge	1.1	..	....	....	....	..
East Walpole	17.5	20	16.7	....	....	..
Ashland Reservoir	27.2	20	16.7	4.6	....	..
Lake Cochituate	8.9	..	....	6.6	....	..
Brookline Pumping Station	....	..	....	6.0	12.5	15
Newton Pumping Station	19.7	20	25	11.6	12.5	15
Chestnut Hill	1.6	..	....	1.1	....	..
Waltham Pumping Station	0.6	20	25	1.3	12.5	15
Moody Street, Waltham	0.6	20	25	....	....	..
Stony Brook Dam	6.4	20	25	6.3	12.5	15
Wrentham	....	..	....	7.0	12.5	10
Franklin	....	..	....	13.3	12.5	10
Milford	....	..	....	14.1	12.5	10
Walpole	....	..	....	2.2	....	..
Millis	....	..	....	21.4	12.5	10
Norwood	....	..	....	4.5	....	..

for 1930. Using such of the data for 1930 as applied to the rainfall stations in existence in 1910, it is possible to indicate the probable error in the 1910 estimate.

Three sets of results are presented: (a) using stations in existence in 1910, (b) using stations in existence in 1930, and (c) using only stations in existence in 1910 but employing the rainfall of 1930. Each set includes computations made by the Thiessen method, a direct average, and a weighted average. In the last two methods the rainfall at Stony Brook Dam, Waltham Pumping Station, and Moody Street has been averaged and used as a single record.

For the 1910 determinations, eleven stations have been employed in the Thiessen method and five stations in the other methods. The Thiessen method gives a somewhat higher result. As shown in Table 3, the range in the rainfall itself, as in the case of the Wachusett watershed, was not great enough to give much variation in the results obtained by the different

methods. A comparison of the 1930 results shows them to be quite consistent, the maximum variation being less than one per cent. Applying the 1930 data to the rainfall stations in existence in 1910 the estimate of mean

FIG. 3.—RAINFALL STATIONS ON CHICOPEE RIVER CATCHMENT AREA.

rainfall is 3 to 5 per cent. higher than when all the available records are used.

Judged by the differences found, it would appear that the direct average is the most practical method for this drainage area.

CHICOPEE RIVER CATCHMENT AREA.

The Chicopee River has a drainage area of 704 square miles above the gaging station at Bircham Bend. Twenty-six rainfall stations are located within this area and, for the most part, they are well distributed. One other station, that at Charlton, was used. This station is about a mile outside the watershed, the nearest station within it being about nine miles distant.

In 1930, there was a considerable range in rainfall on this watershed, varying from 25.69 to 37.60 in. In the southern portion it averaged between 28 and 29 in. while several of the northerly stations registered more than 35 in. of rainfall.

TABLE 5. — MEAN ANNUAL RAINFALL ON THE CHICOPEE RIVER WATERSHED, 1930.

(The percentage errors are based on the assumption that the estimate of rainfall using 27 stations is correct.)

Number of Stations Used.	Rainfall by Direct Average. In.	Percentage Error.	Rainfall by Thiessen Method. In.	Percentage Error.
27	32.48	0	31.79	0
15 (1)	32.30	0.6	32.81	3.2
15 (2)	31.91	1.8	31.42	1.2
9 (1)	32.36	0.4	32.09	0.9
9 (2)	32.45	0.1	31.41	1.2
9 (3)	32.26	0.7	31.10	2.2
5 (1)	29.96	7.8	29.14	8.3
5 (2)	32.72	0.7	32.86	3.4

TABLE 6. — PERCENTAGE WEIGHT ASSIGNED TO RAINFALL STATIONS ON THE CHICOPEE RIVER WATERSHED IN COMPUTATION OF MEAN RAINFALL.

	Number of Stations Employed.															
	27		15 (1)		15 (2)		9 (1)		9 (2)		9 (3)		5 (1)		5 (2)	
Station.	Thiessen Method.	Direct Average.	Thiessen Method.	Direct Average.	Thiessen Method.	Direct Average.	Thiessen Method.	Direct Average.	Thiessen Method.	Direct Average.	Thiessen Method.	Direct Average.	Thiessen Method.	Direct Average.	Thiessen Method.	Direct Average.
Monson	8.04	3.70	8.9	6.67	8.8	6.67	13.4	11.1	....	....	....	....	....	..	13.5	20
West Brookfield	6.41	3.70	...	....	10.3	6.67	17.0	11.1	....	....	....	....	....	..	22.2	20
West Rutland	6.09	3.70	...	....	6.8	6.67	....	....	....	....	12.6	11.1	....	..	....	..
New Braintree	5.92	3.70	9.7	6.67	6.1	6.67	....	....	14.3	11.1	....	....	27.8	20	....	..
Ludlow	5.89	3.70	7.7	6.67	....	....	....	....	....	....	12.1	11.1	....	..	....	..
Warren	5.16	3.70	9.1	6.67	....	....	....	....	....	....	19.7	11.1	....	..	....	..
Bondsville	4.62	3.70	...	....	11.3	6.67	....	....	24.3	11.1	....	....	26.6	20	....	..
North Dana	4.12	3.70	8.3	6.67	....	....	....	....	....	....	10.2	11.1	....	..	25.5	20
Williamsville	4.12	3.70	8.1	6.67	....	....	11.0	11.1	....	....	....	....	19.9	20	....	..
Hubbardston	3.93	3.70	...	....	8.5	6.67	....	....	....	....	9.5	11.1	....	..	....	..
Hardwick	3.89	3.70	...	....	8.1	6.67	10.7	11.1	....	....	....	....	....	..	....	..
Barre	3.88	3.70	4.1	6.67	....	....	....	....	....	....	11.3	11.1	....	..	....	..
Charlton	3.76	3.70	5.6	6.67	3.68	6.67	....	....	7.1	11.1	....	....	....	..	....	..
Petersham	3.76	3.70	...	....	7.1	6.67	5.4	11.1	....	....	....	....	....	..	....	..
Ware Center	3.32	3.70	7.7	6.67	....	....	....	....	....	....	9.1	11.1	....	..	....	..
North Rutland	3.21	3.70	6.4	6.67	....	....	....	....	9.5	11.1	....	....	....	..	20.2	20
New Salem	3.12	3.70	...	....	6.5	6.67	10.6	11.1	....	....	....	....	11.9	20	....	..
Prescott	3.07	3.70	...	....	5.8	6.67	....	....	6.8	11.1	....	....	....	..	....	..
Dana	2.90	3.70	4.5	6.67	....	....	....	....	12.2	11.1	....	....	....	..	....	..
Greenich	2.14	3.70	4.4	6.67	....	....	....	....	....	....	10.4	11.1	13.8	20	....	..
Packardville	2.14	3.70	4.4	6.67	....	....	5.6	11.1	....	....	....	....	....	..	....	..
West Ware	1.99	3.70	...	....	4.7	6.67	12.3	11.1	....	....	....	....	....	..	18.6	20
Enfield	1.97	3.70	...	....	4.2	6.67	....	....	7.5	11.1	....	....	....	..	....	..
Wendell	1.86	3.70	...	....	2.0	6.67	....	....	5.8	11.1	....	....	....	..	....	..
White Valley	1.75	3.70	6.2	6.67	....	....	14.0	11.1	....	....	....	....	....	..	....	..
Shutesbury	1.52	3.70	4.9	6.67	....	....	....	....	....	....	5.1	11.1	....	..	....	..
Coldbrook	1.42	3.70	...	....	6.0	6.67	....	....	12.5	11.1	....	....	....	..	....	..

In analyzing the data for the Chicopee watershed the direct average and the Thiessen method were compared, first using all of the 27 stations and then using various combinations of stations in reduced numbers, picked to give the best geographical distribution. Thus two sets of fifteen stations each (three being used twice) were compared; three sets of nine stations each (using all 27 stations); and finally two sets of only five stations each. Assuming that the estimate of mean rainfall using all the stations is correct, the error obtained by using fewer stations in making the determination can be shown. This is given in Table 5. It will be seen that in six of the eight cases the direct average gives higher results, but in only one instance a higher percentage error, than the Thiessen method. In comparing the direct average and Thiessen method for the same stations, the results are generally in close agreement. On the basis of actual results the Thiessen method does not seem to possess a marked advantage here.

Conclusion.

Somewhat different methods of analysis were used for the three watersheds studied in this paper. The main comparison has been between the direct average and the Thiessen method. The variation in the results here obtained is not great enough to justify the additional work incident to the use of the Thiessen method. The general agreement is due to the relatively large number of stations on each catchment area, their fairly even distribution and the narrow range in the values of rainfall. In Massachusetts where several rainfall stations are usually found on watersheds of even moderate size and where the amount of rainfall does not vary greatly, the use of the Thiessen method, therefore, is probably not warranted, although it may be theoretically more correct.

The courtesy of Mr. George V. White of the Massachusetts Department of Public Health in furnishing the necessary data used in the preparation of this paper is appreciated.

AN AUTOMATIC TRANSFER FERMENTATION TUBE BATTERY FOR DETERMINATION OF B. COLI IN WATER.

BY WILLIAM FIRTH WELLS.*

[*Received September 1, 1932.*]

Numerical precision in the determination of *B. coli* in water has become increasingly important with the rapid extension and development of public drinking-water supplies. Bacterial change is used as a measure of the activity of natural and artificial agencies of pollution and purification in plant operation and control, in sanitary surveys of lakes, streams and coastal waters, and in investigations and experimental work. Since it is a change in relative numbers of *B. coli* rather than a change in kinds of organisms which is significant in sanitary studies and measurements, fine qualitative distinctions gained through elaboration of the individual test for *B. coli* contribute but little, as compared to the numerical precision gained by running tests on a large number of samples or many tests on one sample. If through stringencies of laboratory requirements a choice must be made, it should be for numerical precision rather than qualitative distinction.

Presumptive Test. Many modifications of the presumptive test for *B. coli* have been proposed as simplifying laboratory procedure without sacrificing the essential refinements for detection of this organism. Much ingenuity has been displayed in the development of specific media, fermentable only by *B. coli* without interfering with its growth. Numerous media have been employed with apparent local success, but the continuing advocation of new media would seem to testify to a lack of general acceptability of the media so far evolved.

There has recently been proposed the addition to Standard Methods of Water Analysis of a system of double planting which offers a new approach toward simplification of the test for *B. coli*. This proposal frankly acknowledges the failure of any one single medium to combine successfully the different qualities demanded in the detection of *B. coli*. It recognizes especially two basic qualities, *enrichment* and *selection*, which, if not mutually exclusive, are more perfectly attainable separately.

Double planting as proposed by Jordan[1] involves one of two procedures. In the first procedure samples of the water analyzed are inoculated first into lactose broth which serves as a primary enrichment medium. All tubes showing gas within 48 hours are next transferred into brilliant-green lactose-bile which serves as a specific secondary confirmatory medium. All secondary tubes showing ten or more per cent of gas in 48 hours are then recorded as positive.

In the second procedure, which is supplementary to the first, a primary selective tube (brilliant-green lactose-bile) is inoculated in parallel with

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each primary enrichment tube (lactose broth). All primary selective tubes (brilliant-green lactose-bile) showing ten or more per cent. of gas within 48 hours are then recorded as positive without further confirmation.

Jordan's first procedure differs essentially from the partially confirmed test of Standard Methods, in the use of a liquid specific medium (brilliant-

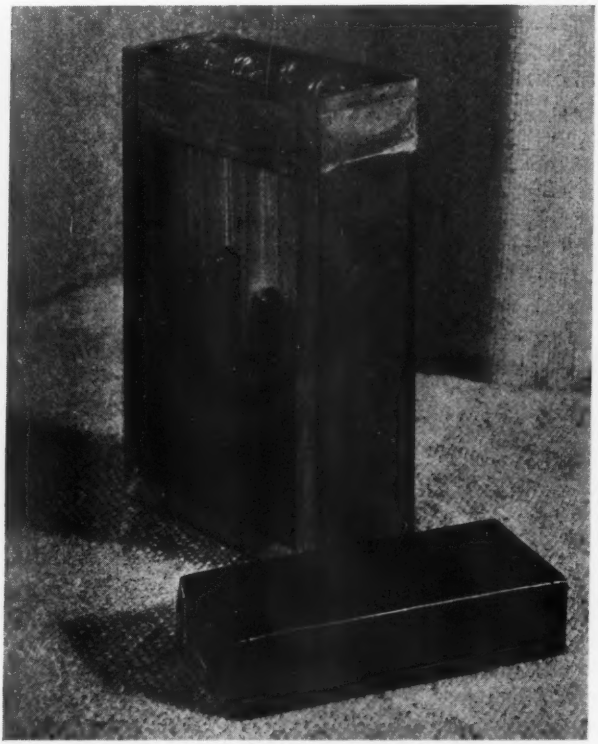

FIG. 1.—VIEW OF BATTERY OF TWO ROWS OF FIVE TUBES EQUIPPED WITH SIPHONS.

green lactose-bile), in place of a solid specific medium (endo or eosine-methylene-blue agar) for the confirmation of organisms fermenting lactose broth. Economy and convenience rather than superior diagnostic value are the object of this substitution.

A more radical departure from Standard Methods is suggested in Jordan's second procedure, in which it is assumed that only the more virile organisms ferment the selective medium (brilliant-green lactose-bile) on primary inoculation, and that diagnostic significance can be attached to

primary and secondary fermentation of the selective medium, i.e. fermentation requiring and not requiring rejuvenation.

Transfer Battery. It is not the purpose of this paper to judge the merits of different media or to discuss the theory of double planting, but to introduce an automatic transfer device which simplifies the technique of double planting. This device is illustrated in Figures 1 and 2 as a twin battery of

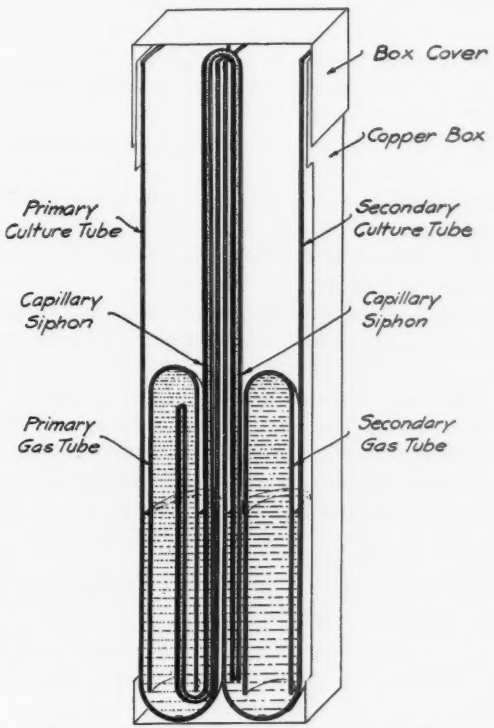

FIG. 2.—SECTION THROUGH BATTERY AND BOX.

fermentation tubes connected by a capillary siphon. The siphon passes from the closed or gas collection arm of the primary, or enrichment, tube to the open arm of the secondary, or selective, tube and constitutes the automatic transfer feature. Inoculation of the selective tube begins as soon as gas is evolved in the enrichment tube, the amount of material transferred being determined by the proportions of the siphon.

The routine use of siphons is made simple by placing the batteries of fermentation tubes in covered copper boxes with open side walls. This does away with the use of troublesome cotton plugs, racks and baskets.

The enrichment medium is added to the front row of tubes and the selective medium to the back row. A Wassermann tube is hooked onto the short leg of the siphon which is then dropped into tubes straddling the rows. Tubes fill when sterilized. Experience with the siphons has demonstrated their positive action.

This automatic feature possesses several advantages over manual transfer. Besides the matter of convenience and economy, these advantages may be listed as follows:

1. The selective medium is inoculated with a definite portion of vigorous culture from the enrichment medium.

2. Inoculation takes place at the time of gas production only and is cut off before overgrowth occurs.

3. Prompt inoculation of the selective medium shortens the test period.

4. The labor saved may be gainfully employed to multiply the number of tubes used and thus attain greater numerical precision.

5. Pure cultures may be isolated or automatic subculture tests made by the use of multiple siphons.

The importance of inoculating a large dose of the enrichment culture into the selective tube at the moment of gas production was pointed out by Prescott,[2] who showed that after gaining ascendancy *B. coli* may be overgrown by streptococci. Immediate inoculation when gas forms avoids this source of error. Ordinarily, *B. coli* ferment lactose broth earlier than do the common spore-forming anaërobes. The latter, therefore, may be excluded from the secondary tube if siphonage is automatically cut off before they have multiplied in the primary tube. The same principle also applies to the separation of other slower growing forms which might interfere with later steps of confirmation.

Withdrawal of the culture from the upper part of the closed arm of the lactose-broth fermentation tube, i.e. from a point most remote from the point of inoculation, avoids transfer of aërobic organisms which often form a scum over the surface of lactose broth and through which, by ordinary transfer procedures, *B. coli* must be withdrawn on a wire. The motility of *B. coli* insures their invasion of the closed arm, possibly leaving behind other non-motile forms.

By transferring cultures from the most promising point and at the most promising time, it has been found in practice that the amount of gas formation in the secondary tube is more typical of pure *B. coli* cultures than it is in the primary tube and that subsequent identification on solid media is rendered more definite. Anabiotic conditions are especially likely to occur in the first tube where, as inoculated, *B. coli* are decidedly in the minority; though given time and otherwise favored in the secondary, or selective, tube, they may readily outstrip all competition.

The saving in time elapsing between the time of immediate automatic transfer, when gas begins to form, and the time when the bacteriologist in

the course of laboratory routine would make transfers may be almost twenty-four hours should gas form shortly after the routine daily transfer time.

The saving of labor resulting from the use of the battery boxes has been emphasized elsewhere[3] but cannot be fully appreciated without actual experience with them. Excellent copper boxes holding ten 6-in. by ¾-in. tubes for making 1-cc. inoculations may be had at $1.00 each, and larger boxes for 10-cc. inoculations at $1.25. These boxes constitute a useful and attractive part of laboratory equipment, aiding routine analyses much as index cards do most office systems. Only by some such systematizing of routine is it practicable to obtain with reasonable facility the volume of results desirable for quantitative precision.

Besides providing automatic transfer of positive tubes the siphon arrangement simplifies the problem of mass transfer of negative tubes. Tilting the box causes one set of tubes to siphon over into the other. If, at the end of twenty-four hours, gas production has been restrained by interference of other organisms in the enrichment medium, a mere tilting of the box will transfer the enriched culture to the selective secondary medium, thus securing the major advantage of Jordan's second procedure without the complications involved in duplicate primary planting. With less equipment, time and labor, the one procedure secures the benefits of both.

Summary. The automatic transfer fermentation tube battery described in this paper provides a convenient and economical device for double planting, by saving in time, labor and materials, and permits the multiplication of tests for numerical precision by simplifying the individual test necessary for the determination of *B. coli* in water.

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[2] Prescott, S. C., Science, N. S., 1902, 16, 671.
[3] Wells, W. F., Am. Jour. Pub. Health, 1918, 8, 904; Science, N. S., 1910, 31, 557.

DOMESTIC FLOW AS AFFECTING METER REGISTRATION AND WATER REVENUE.

A Preliminary Study.

BY H. W. GRISWOLD* AND W. A. GENTNER.†

[*Read September 28, 1932.*]

The loss in revenue due to the under-registration of meters is a "hardy perennial" in the water-works garden, for the ability of water meters to record accurately the quantity of water passing through them is still of paramount importance to utilities whose income is dependent on such registrations. In these times of income reduction, due to business depression, keen attention is being paid to stopping gaps in the efficiency fence and to searching out legitimate sources of income that were overlooked in more prosperous times. In this connection the Water Bureau of the Metropolitan District of Hartford has directed its efforts to a study of the performance of meters under actual operating conditions with special reference to its effect on revenue production.

Modern plumbing equipment, requiring relatively high rates of flow for satisfactory operation, is largely responsible for the development of large-capacity meters, capable of handling high rates of flow with minimum increase in pressure losses through the meter and without sacrificing accuracy of registration. As a result of improvements in design and construction, the performance of present-day meters is far superior to that of the older models. The problem of under-registration at low flows still persists, however, although to a somewhat smaller degree.

The registration requirements of new disk meters, as set forth in the specifications adopted by the New England Water Works Association and the American Water Works Association, provide for registration of not less than 98 per cent., nor more than 102 per cent., of the water actually passed through the meter when tested within the "normal test-flow limits," and for recording not less than 90 per cent. of the actual flow when tested at the "minimum test-flow." The recently adopted specifications of the Public Service Commission of the State of New York require registration of not less than 98 per cent., nor more than 101 per cent., within the "normal test-flow limits," and a steady uniform movement of the pointer on the initial dial during at least a five-minute period at the "minimum test-flow."

The "normal test-flow limits" and "minimum test-flow" are as listed on next page.

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Size. Inches.	Normal Test-Flow Limits. Gallons per minute.	Minimum Test-Flow. Gallons per minute.
5/8	1 to 20	1/4
3/4	2 to 34	1/2
1	3 to 53	3/4
1½	5 to 100	1½
2	8 to 160	2
3	16 to 315	4
4	28 to 500	7
6	48 to 1 000	12

Endurance Test of New Meters.

Varying statements are made as to the quantity of water which may be passed through a new meter before an impairment in registration occurs. An endurance test now being made in Hartford on a group of new ¾-in. disk meters has permitted some study of this problem.

This particular test is the outgrowth of an originally planned endurance run on fifteen ⅝- and ¾-inch meters, connected in series and run open-ended for three months, during which some 325 000 cu. ft. of water passed through them, at an average rate of 2.55 cu. ft. per minute, without any appreciable impairment in the registration of the meters. The test was finally abandoned in favor of one which would provide an intermittent flow of water and thus more nearly approach actual operating conditions. In the test now being made three ¾-in. meters, selected from the original test group of fifteen, are connected in series, and water after passing through them is delivered through about 45 ft. of ¾-in. pipe to a Sloane Flush Valve, which operates automatically at a rate of ten 4-second flushes per minute, using about 0.17 cu. ft. of water per flush, which is equivalent to a rate of approximately 20 g.p.m.

The performance of the Sloan Valve used in this work has proved very satisfactory throughout the severe test to which it has been subjected. Aside from the replacement of packings and occasional minor adjustments, the valve required no attention in six months of continuous service, during which over 177 000 cu. ft. of water were discharged, requiring, at the rates then employed, some 713 000 operations of the valve. Following this six months' service, the valve began to give trouble and was replaced by another of the same make and type, which has proved even more successful than its predecessor, over 223 000 cu. ft. of water (requiring over 1 300 000 flushing operations) having been discharged through it.

Except for necessary shutdowns due to replacing of valve packings, testing meters, etc., this test has been run continuously since April 7, 1931. During that period some 400 000 cu. ft. of water have passed through the meters, making with the original test approximately 725 000 cu. ft. up to date.

A comparison of tests of the meters in their present condition and when new follows:

Orifice.	Meter "A".		Meter "B".		Meter "C".	
	New.	After Passing 725 000 cu. ft.	New.	After Passing 700 000 cu. ft.	New.	After Passing 725 000 cu. ft.
1/32	Registers	Registers	Registers	Registers	Registers	Does not Register
1/16	97%	97.0%	94.7%	98.0%	97%	95.0%
1/4	—	100.7%	—	101.8%	—	102.2%
Full Flow	99%	99.1%	100.0%	101.1%	100.8%	100.8%

The registration of each of these meters has held up exceptionally well, Meter "C" being the only one to fall below new meter requirements. Up to date, Meter "A" has proved the best all around meter; Meter "B" after passing some 25 000 cu. ft. less than the other meters is inclined to be noisy and has required four replacements of the bottom plate due to the water hammer developed by the quick closing of the flushometer valve. As already noted, Meter "C" failed to register on the 1/32 orifice, a condition which developed at some time after 675 000 cu. ft. had been passed. The performance of these three meters indicates conclusively that meters of high quality, as they are made today, should give many years of service without serious impairment of registration. There is evidence, however, that meters in actual service, particularly those manufactured 15, 20 and 30 years ago, do not stand up as well as this test would indicate.

Performance of Old Meters.

In testing meters removed from service, those giving a satisfactory registration test are the exception rather than the rule, this observation applying to all makes of meters. Because of this condition, an extended study into the performance of old meters in service in The Metropolitan District of Hartford is being made, and this paper is in the nature of a preliminary report on the collection of data bearing on the problem, together with a few conclusions which seem to have general application.

The Hartford water system has been fully metered since 1904, and on January 1, 1932, there were in service 26 204 meters, the 1931 earnings from which amounted to $964 793.45, an average of $36.82 for each meter in service, regardless of size. Based on a careful study of revenue from meters of various sizes, made several years ago, it is estimated that normal present-day percentage revenue by size of meter averages for Hartford about as follows:

Size of Meter. Inches.		Number in Use.	Annual Revenue. Per cent.
5/8	billed	12 707	20
3/4	billed	10 144	33
1	semi-annually	2 429	22
1¼ and 1½	semi-annually	457	10
2 and over	billed monthly	467	15
		26 204	100

Since the 5/8- and 3/4-in. groups contain the largest number of units (about 87 per cent. of the total number in use), since meters of these two groups bring in a substantial part of the annual revenue (53 per cent.) and since a considerable portion of these revenue-producing meters have seen years of service, the studies reported in this paper were confined to old meters of 5/8- and 3/4-in. size. Inasmuch as preliminary tests made on old meters taken directly from service indicated the possibility of appreciable under-registration at the lower rates of flow, it seemed desirable to get accurate first-hand information on the rates at which water is ordinarily used, in order to determine what proportion of the total quantity is drawn at low rates at which under-registration was suspected. For this purpose

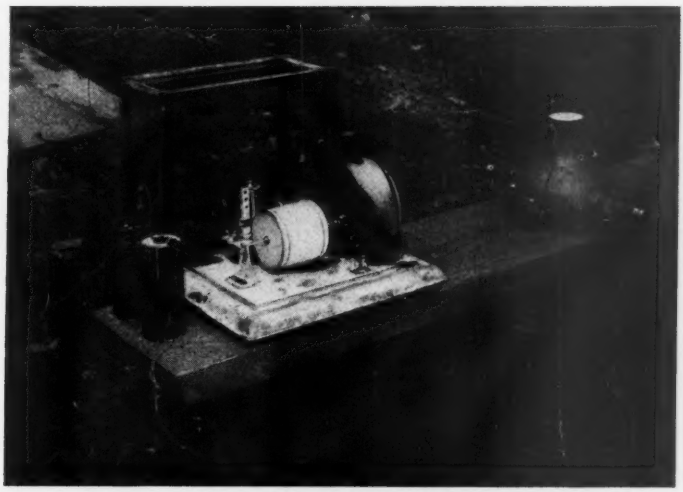

FIG. 1.— RECORDING DEVICE (Friez Rain Gage Recorder) ON 3/4-IN. METER.

a number of typical single, two-family and three-family houses were selected from which 24-hour records were secured, showing the rates at which water was used.

In the selection of the classes of houses special care was taken to include only those from which a large proportion of the water revenue is derived. For this reason, the more pretentious class of residences was excluded from consideration, for while the use of water at such premises is usually considerably more than in smaller houses of the same general type, the total income derived from them as a class is far less than from the considerably greater number of houses making up the smaller type.

The houses selected may be classified as follows:

Type of House.	Number of Occupants.	Number of Rooms.	Average Valuation.
Single	5	6–8	$7 000 to $10 000
Two-family	8	10–14	$15 000 to $18 000
Three-family	12	15–18	$20 000 to $25 000

Recording Rate of Flow.

Various types of apparatus have been employed by the Bureau from time to time for recording rates of flow through meters. The earliest instrument (Fig. 1) which was used (about 1915) consisted of a standard

Fig. 2.— Voltmeter Recording Device on ¾-In. Meter.

Friez rain gage,* which was put into circuit with two or more dry cells and a contact which would close the circuit at each revolution of one of the meter dials. The one-foot dial was used most generally for this purpose. The record obtained was in the form of a series of steps; 5 steps out and 5

*Saville, C. M. Journal N.E.W.W.A., 32 (1918), p. 329.

steps back, each step representing one cubic foot. The limitations of the instrument were that nothing less than a total flow of one cubic foot could be recorded, and, further, that only one meter could be tested at a time. As it was desirable to record rates of flow through compound meters another piece of apparatus was developed, which had the same limitations,

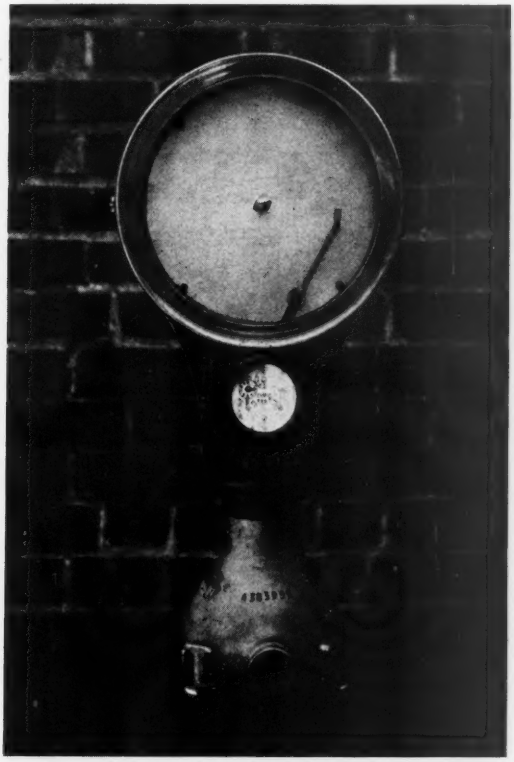

FIG. 3.— NEPTUNE METER CO. RECORDING REGISTER ON ¾-IN. METER.

however, as the first, insofar as recording rates of flow for a quantity less than one cubic foot was concerned.

In the second apparatus, a standard Bristol voltmeter was used as the recording device (Fig. 2). This instrument uses a circular chart with the zero position of the pen about midway of the radius. The pen is deflected in one direction for plus flows of current and in the opposite direction for minus flows. With this instrument it was not possible to employ the simple contact between wire and meter-dial pointer, which had been used

with the rain gage, for the reason that, in the case of a long plus contact, no minus contact could be recorded during that period. A special contact

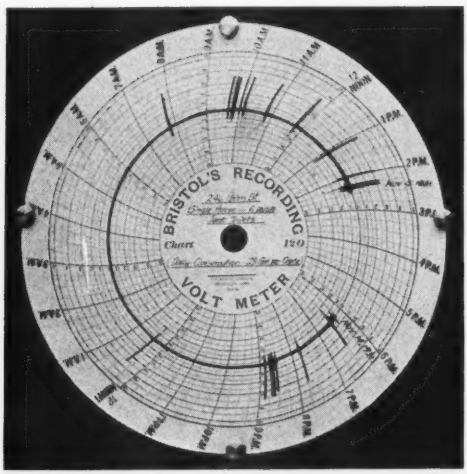

FIG. 4.— VOLTMETER RECORDING DEVICE CHART.

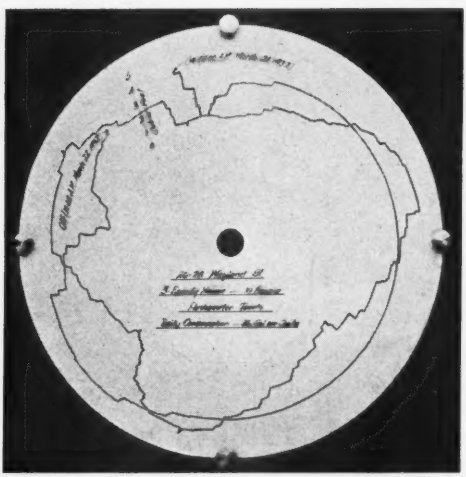

FIG. 5.— NEPTUNE METER CO. RECORDING METER CHART.

device was developed, using a set of points from a telephone instrument, so arranged that a lever was deflected by the meter-dial pointer until the end of the lever slipped by the end of the pointer and, as the lever was pulled

back into position by a coil spring, it momentarily closed the telephone contacts. In order that the current might be on for an appreciable time, a small dash pot was used to slow down the action of the coil spring. The typical record chart for a test of a compound meter shows a series of points or swings to one side of the zero voltage line, each point representing one revolution of one dial of the small meter. For larger flows there is a series of points on the opposite side of the zero voltage, each of which represents one revolution of one of the dials of the large meter. Opposite the points for the large meter, there are a few points representing the water passed by the small meter during operation of the large meter.

When the collection of data on rates of flow through $\frac{5}{8}$- and $\frac{3}{4}$-in. meters was started, it was found that neither of the above instruments was suitable because both measure in minimum units of one cubic foot, so that, on all of the measurements of flow on small meters, an instrument (Fig. 3) developed by the Neptune Meter Company was used by courtesy of Mr. R. K. Blanchard. This device consists of a revolving chart on which a line is traced by a pen actuated by the meter-disk spindle through special gearing. From the records obtained with this instrument, rates of flow can be taken to almost any desired degree of precision. The limitations of this tester are that it can be used only for Trident meters and for recording the rate through only one meter at a time. Another instrument for recording rates of flow through meters is now under development by the Bureau, but is still in the experimental stage. Typical charts traced by the voltmeter and the Neptune instrument are shown in Figures 4 and 5 respectively.

Discussion of Results.

Summaries of the actual rates at which water passed through each size of meter in each type of house are shown in Tables 1–4. The daily per capita consumption given in these tables, especially for single houses, is somewhat lower than might be expected. This is probably due to the fact that the results are based on a single day's use of water, and furthermore that these observations were made in the early spring with no outside use of water for gardens. It is believed that 35 to 40 gal. per capita per day is a fair year round average for a single house.

Table 5 shows, for each size of meter and type of house, the use of water at various rates as a percentage of the total quantity drawn. A study of this table indicates that in houses equipped with tank toilets from 27 to 50 per cent. of the total amount of water is used at rates less than 1 g.p.m., and that from 38 to 78 per cent. is used at rates less than 2 g.p.m. In houses having flushometer toilets the percentage of use at low rates is somewhat less and ranges from 10 to 33 per cent. for rates less than 1 g.p.m., and from 20 to 55 per cent. for rates less than 2 g.p.m. It is evident, therefore, that a considerable amount of water is used at the lower rates and that the

accuracy of registration at rates of flow less than 2 g.p.m. is of great importance.

Table 6 shows an estimate of the amount of water used in each type of house at various rates. Values in this table are based on the averages of the observed drafts shown in Tables 1–4 and were used in estimating the amount of unrecorded water and loss in revenue to be discussed later. With the actual rates at which water is delivered through $\frac{5}{8}$- and $\frac{3}{4}$-in.

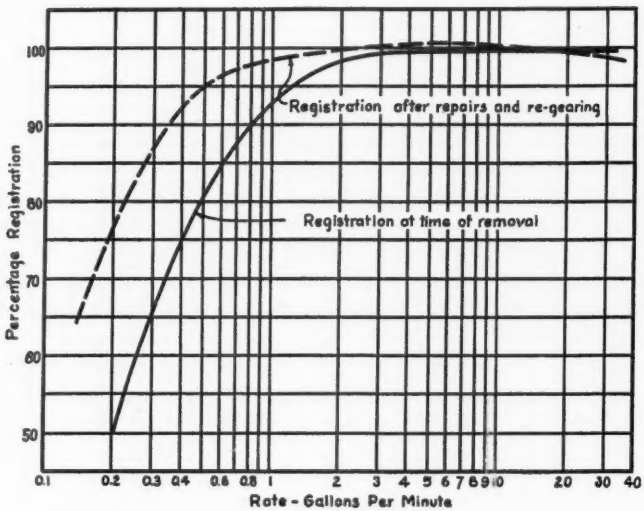

FIG. 6.— PERCENTAGE REGISTRATION OF $\frac{5}{8}$-IN. AND $\frac{3}{4}$-IN. DISK METERS REMOVED FROM SERVICE FOR TESTING.

meters established, attention is now directed to the average accuracy of registration at these rates, as shown in Figure 6. The solid-line curve in this diagram is based on tests of a number of $\frac{5}{8}$- and $\frac{3}{4}$-in. meters directly after their removal from service. A summary of these tests is given in Table 7. Because the averages for $\frac{5}{8}$- and $\frac{3}{4}$-in. meters were so nearly the same, a single curve was used to show the percentage registration for both sizes of meters. No claim is made that this curve represents a true average registration of all meters in service. As a matter of fact, meters showing abnormally low registration were purposely omitted from consideration in development of the curve.

The total amount of unrecorded water and the resulting loss in revenue for each type of house are shown in Tables 8 and 9. The figures in these tables were obtained by applying the percentage registration of the meters (Fig. 6) to the various rates and quantities of water used, as shown in Table 6.

TABLE 1.—⅝-IN. METERS—USE OF WATER IN HOUSES HAVING TANK TOILETS, (24-HOUR RECORDS).

LOCATION OF HOUSE.	No. People	CU. FT. RECORDED AT GIVEN RATES—GAL./MIN.							Total Cu. Ft.
		< ½.	½-1.	1-2.	2-3.	3-4.	4-5.	5-10.	
SINGLE HOUSES.									
175 Ridge Road	2	1.8	0.2	0.4	....	....	1.3	1.5	5.2
185 Linnmoore St.	3	2.3	0.8	2.1	1.9	3.0	....	4.1	14.2
105 Brunswick Ave.	4	2.1	2.7	1.6	0.3	1.9	1.8	3.4	13.8
432 Campfield Ave.	4	1.1	1.4	1.0	....	4.5	2.4	2.1	12.5
Total (4 houses)	13	7.3	5.1	5.1	2.2	9.4	5.5	11.1	45.7
Percentage	..	15.9	11.2	11.2	4.8	20.6	12.0	24.3	100.0
Average daily consumption—26 gallons per capita.									
TWO-FAMILY HOUSES.									
27-9 Argyle Ave.	4	5.0	1.2	5.0	4.3	5.4	2.5	2.4	25.8
193-5 Wolcott Hill Road	5	2.4	5.7	10.8	0.9	0.2	....	....	20.0
92-4 Morningside St.	6	2.9	3.5	4.6	2.3	5.7	3.0	3.2	25.2
66-8 Dover Road	6	2.6	1.5	2.5	....	1.6	1.9	2.2	12.3
384-6 So. Quaker Lane	7	0.9	4.9	4.3	2.6	13.3	7.2	3.9	37.1
546-8 Blue Hills Ave.	10	10.5	8.5	19.8	6.7	3.6	1.2	....	50.3
1162 New Britain Ave.	12	3.2	9.3	3.0	0.6	6.6	2.4	4.1	29.2
Total (7 houses)	50	27.5	34.6	50.0	17.4	36.4	18.2	15.8	199.9
Percentage	..	13.8	17.3	25.0	8.7	18.2	9.1	7.9	100.0
Average daily consumption—30 gallons per capita.									
THREE-FAMILY HOUSES.									
233-5 Campfield Ave.	13	5.2	20.6	20.8	3.8	3.3	6.9	33.0	93.6
Total (1 house)	13	5.2	20.6	20.8	3.8	3.3	6.9	33.0	93.6
Percentage	..	5.6	22.0	22.2	4.1	3.5	7.4	35.2	100.0
Average daily consumption—54 gallons per capita.									

TABLE 2.—⅝-IN. METERS—USE OF WATER IN HOUSES HAVING FLUSHOMETER TOILETS, (24-HOUR RECORDS).

LOCATION OF HOUSE.	No. People	CU. FT. RECORDED AT GIVEN RATES—GAL./MIN.								Total Cu. Ft.
		< ½.	½-1.	1-2.	2-3.	3-4.	4-5.	5-10.	25-30.	
SINGLE HOUSES.										
24 White Ave.	4	2.0	2.1	1.4	3.6	0.5	2.4	....	6.4	18.4
45 Woodlawn St.	4	....	0.3	2.0	0.9	....	....	....	3.9	7.1
184 Mountain Road	5	5.1	4.1	2.8	1.2	7.0	1.2	3.3	7.6	32.3
183 Palm St.	6	0.2	1.5	3.1	2.1	0.6	....	3.3	5.0	15.8
Total (4 houses)	19	7.3	8.0	9.3	7.8	8.1	3.6	6.6	22.9	73.6
Percentage	..	9.9	10.9	12.6	10.6	11.0	4.9	9.0	31.1	100.0
Average daily consumption—29 gallons per capita.										
TWO-FAMILY HOUSES.										
77-9 Victoria Road	6	2.5	1.0	3.4	2.0	1.9	2.4	0.7	20.3	34.2
Total (1 house)	6	2.5	1.0	3.4	2.0	1.9	2.4	0.7	20.3	34.2
Percentage	..	7.3	2.9	10.0	5.8	5.6	7.0	2.0	59.4	100.0
Average daily consumption—42.7 gallons per capita.										

TABLE 3.—¾-IN. METERS.—USE OF WATER IN HOUSES HAVING TANK TOILETS, (24-HOUR RECORDS).

LOCATION OF HOUSE.	No. People	CU. FT. RECORDED AT GIVEN RATES—GAL./MIN.							Total Cu. Ft.
		<½.	½-1.	1-2.	2-3.	3-4.	4-5.	5-10.	
TWO-FAMILY HOUSES.									
192-4 Ashley St.	6	5.6	3.8	11.1	4.0	4.4	1.8	1.5	32.2
320 White St.	8	7.9	0.1	1.8	7.2	2.1	3.6	6.0	28.7
141-3 Barker St.	9	8.3	9.2	1.1	4.0	7.8	5.9	3.5	39.8
90-2 Beacon St.	11	11.1	7.6	3.4	2.7	5.8	5.4	4.2	40.2
Total (4 houses)	34	32.9	20.7	17.4	17.9	20.1	16.7	15.2	140.9
Percentage	..	23.3	14.7	12.4	12.7	14.2	11.9	10.8	100.0
Average daily consumption—33 gallons per capita.									
THREE-FAMILY HOUSES.									
112-4 Putnam St.	4	4.5	2.5	6.1	1.2	0.4	....	....	14.7
160-2 Beacon St.	6	2.6	1.6	3.2	3.0	1.8	5.7	4.3	22.2
347-9 Hillside Ave.	6	14.1	9.9	5.3	3.9	2.8	....	....	36.0
129-31 Earl St.	8	25.9	2.2	10.9	0.6	....	....	....	39.6
203-5 Homestead Ave.	11	3.3	14.7	18.4	3.9	1.7	1.8	0.8	44.6
93-5 Magnolia St.	14	7.7	10.5	23.8	5.6	0.8	....	0.7	49.1
54-6 Henry St.	17	12.7	4.3	5.7	11.3	5.5	1.2	0.8	41.5
10-12 Dorothy St.	26	11.3	34.4	17.6	4.5	3.3	1.7	3.0	75.8
Total (8 houses)	92	82.1	80.1	91.0	34.0	16.3	10.4	9.6	323.5
Percentage	..	25.4	24.8	28.2	10.5	5.0	3.2	2.9	100.0
Average daily consumption—26.5 gallons per capita.									

TABLE 4.—¾-IN. METERS—USE OF WATER IN HOUSES HAVING FLUSHOMETER TOILETS, (24-HOUR RECORDS).

LOCATION OF HOUSE.	No. People	CU. FT. RECORDED AT GIVEN RATES—GAL./MIN.									Total Cu. Ft.
		<½.	½-1.	1-2.	2-3.	4-5.	5-10.	5-10.	10-15.	25-30.	
SINGLE HOUSES.											
149 Ridgefield St.	3	1.1	2.5	3.9	2.4	2.3	2.4	2.1	...	23.4	40.1
136 Four Mile Road	4	0.9	1.0	1.4	0.6	2.5	...	...	...	11.0	17.4
126 Ridgewood Road	5	20.1	2.3	1.8	5.4	12.9	5.0	4.5	2.8	1.8	56.6
226 No. Quaker Lane	5	1.8	0.8	1.2	1.9	0.8	1.8	5.4	2.9	19.0	35.6
Total (4 houses)	17	23.9	6.6	8.3	10.3	18.5	9.2	12.0	5.7	55.2	149.7
Percentage	..	15.9	4.4	5.5	6.9	12.4	6.2	8.0	3.8	36.9	100.0
Average daily consumption—66 gallons per capita.											
TWO-FAMILY HOUSES.											
175 Ridgefield St.	2	0.7	4.0	2.8	0.6	2.4	0.6	4.8	...	10.0	25.9
Total (1 house)	..	0.7	4.0	2.8	0.6	2.4	0.6	4.8	...	10.0	25.9
Percentage	..	2.7	15.4	10.8	2.3	9.3	2.3	18.5	...	38.7	100.0
Average daily consumption—97 gallons per capita.											
THREE-FAMILY HOUSES.											
26-8 Wayland St.	10	9.0	4.5	4.8	6.7	5.8	3.1	...	...	12.2	46.1
99-101 Preston St.	11	6.0	6.1	27.0	4.3	2.5	1.2	...	...	31.2	78.3
108-10 Pembroke St.	13	5.4	9.5	12.0	5.6	1.2	...	...	...	21.0	54.7
226-8 So. Quaker Lane	13	19.2	17.3	19.1	1.7	1.2	...	...	...	11.5	70.0
635-7 Garden St.	15	11.4	13.9	7.1	0.3	3.4	...	5.4	...	19.1	60.6
Total (5 houses)	62	51.0	51.3	70.0	18.6	14.1	4.3	5.4	...	95.0	309.7
Percentage	..	16.5	16.6	22.6	6.0	4.6	1.4	1.7	...	30.6	100.0
Average daily consumption—37.5 gallons per capita.											

In houses with tank toilets, from 7 to 12 per cent. of the total amount of water passing through the meter apparently remains unrecorded, resulting in revenue losses (at 20c per 1 000 gal.) of from $0.43 to $2.58 per meter per year. In houses with flushometer toilets, unrecorded water runs from

TABLE 5.—PERCENTAGE OF TOTAL QUANTITY OF WATER USED AT VARIOUS RATES.

⅝-IN. METERS.

Rate Gallons Per Minute.	HOUSES WITH TANK TOILETS.						HOUSES WITH FLUSHOMETER TOILETS.			
	4 SINGLE 13 People.		7 TWO-FAMILY 50 People.		1 THREE-FAMILY 13 People.		4 SINGLE 19 People.		1 TWO-FAMILY 6 People.	
	%	Acc.* %	%	Acc. %	%	Acc. %	%	Acc. %	%	Acc. %
Less than ½	15.9	15.9	13.8	13.8	5.6	5.6	9.9	9.9	7.3	7.3
½–1	11.2	27.1	17.3	31.1	22.0	27.6	10.9	20.8	2.9	10.2
1–2	11.2	38.3	25.0	56.1	22.2	49.8	12.6	33.4	10.0	20.2
2–3	4.8	43.1	8.7	64.8	4.1	53.9	10.6	44.0	5.8	26.0
3–4	20.6	63.7	18.2	83.0	3.5	57.4	11.0	55.0	5.6	31.6
4–5	12.0	75.7	9.1	92.1	7.4	64.8	4.9	59.9	7.0	38.6
5–10	24.3	100.0	7.9	100.0	35.2	100–0	9.0	68.9	2.0	40.6
25–30	....	.....	....	.....	....	.....	31.1	100.0	59.4	100.0

*Accumulative.

¾-IN. METERS.

Rate Gallons Per Minute.	HOUSES WITH TANK TOILETS.				HOUSES WITH FLUSHOMETER TOILETS.					
	4 TWO-FAMILY 34 People.		8 THREE-FAMILY 92 People.		4 SINGLE 17 People.		1 TWO-FAMILY 2 People.		5 THREE-FAMILY 62 People.	
	%	Acc. %	%	Acc. %	%	Acc. %	%	Acc. %	%	Acc. %
Less than ½	23.3	23.3	25.4	25.4	15.9	15.9	2.7	2.7	16.5	16.5
½–1	14.7	38.0	24.8	50.2	4.4	20.3	15.4	18.1	16.6	33.1
1–2	12.4	50.4	28.2	78.4	5.5	25.8	10.8	28.9	22.6	55.7
2–3	12.7	63.1	10.5	88.9	6.9	32.7	2.3	31.2	6.0	61.7
3–4	14.2	77.3	5.0	93.9	12.4	45.1	9.3	40.5	4.6	66.3
4–5	11.9	89.2	3.2	97.1	6.2	51.3	2.3	42.8	1.4	67.7
5–10	10.8	100.0	2.9	100.0	8.0	59.3	18.5	61.3	1.7	69.4
10–15	....	.....	....	.....	3.8	63.1	....	61.3	....	69.4
25–30	....	.....	....	.....	36.9	100.0	38.7	100.0	30.6	100.0

5 to 8 per cent. of the total amount used, and the resulting loss in revenue ranges from $0.52 to $2.70 per meter per year. If $0.50 is taken as a fair average loss per year for all ⅝ and ¾-in. meters in service, the total loss in revenue for this class of meters alone would amount to over $11 000 per year in the Hartford system. It seems probable that the loss for water delivered but unrecorded by the meter is considerably more than this amount, and may run possibly as high as 5 per cent. of the total revenue.

In an effort to reclaim a portion of this revenue, extensive changes

were made in the method of testing meters. The shop equipment for testing meters consists of a Neptune Meter Company testing bench, which will take at one time eight ⅝-in. meters, or seven ¾-in. meters.

TABLE 6.—ASSUMED AVERAGE USE OF WATER BASED ON ACTUAL OBSERVATIONS GIVEN IN TABLES 1–4.

Rate Gal. per Minute.	CUBIC FEET OF WATER USED PER DAY.					
	Tank Toilets.			Flushometer Toilets.		
	Single.	2-Family.	3-Family.	Single.	2-Family.	3-Family.
Less than ½	1.8	3.9	10.3	1.8	2.5	10.2
½–1	1.3	4.9	10.0	2.0	1.0	10.2
1–2	1.3	7.1	11.4	2.3	3.4	14.0
2–3	0.4	2.5	4.2	2.0	2.0	3.7
3–4	2.4	5.2	2.0	2.0	1.9	2.8
4–5	1.4	2.6	1.3	0.9	2.4	0.9
5–10	2.8	2.3	1.2	1.7	0.7	1.1
10–15	...	...	...	...	...	...
15–20	...	...	...	...	...	...
20–25	...	...	...	...	...	...
25–30	...	...	...	5.7	20.3	19.0
Total.	11.4	28.5	40.4	18.4	34.2	61.9

TABLE 7.—SUMMARY OF TESTS ON METERS TAKEN DIRECTLY FROM SERVICE.

No. of Meters Tested.	Water Passed Since Last Test. Cu. Ft.	PERCENTAGE REGISTRATION.				
		1/12-in.	1/8-in.	¼-in.	½-in.	Full Flow.
⅝-IN. METERS. 13	88.385	Reg.	85.8	98.6*	99.4*	99.5
¾-IN. METERS. 15	206.100	Reg.	85.9	....	....	99.6
Plotting points for ⅝- and ¾-in. meters. (Fig. 6.)		..	85.8	98.6	99.4	99.5

*Average for 7 meters only.

The water discharged through the meters under test passes through a quick-closing valve, through an orifice in a Mueller multiple-orifice valve and through overhead piping into a 10-cu. ft. steel tank mounted on platform scales. The initial water pressure available for test is between 100 and 105 lb. per sq. in. The outlet pressure on the orifice valve varies with the number and type of meters under test, so that the rate of flow at any

given orifice opening has been variable. To correct this condition, a pressure-reducing valve was installed on the outlet end of the string of meters under test. This valve was set by trial at 40 lb. per sq. in. pressure, which gives reasonably constant rates of flow for the smaller orifices. For full-flow test, the outlet pressures drop to from 7 to 10 lb. per sq. in., so that there is still some variation in the rates for these test flows, but it is thought that these variations are not important.

In running a series of tests on meters at low rates of flow it seemed desirable to have a more accurate measure than could be obtained by weighing on high-load scales when the total quantity was only one cubic foot. Accordingly, it was decided to make the one-cubic-foot test volumetrically, using a measuring can similar to those employed in testing gasoline pump meters. These one-cubic-foot cans are also being used in making accuracy tests on meters on the consumers' premises.

Special efforts have been made during the last few years to bring the meter-testing schedule into conformity with the Public Utilities Commission requirement, that all meters be tested at intervals not exceeding five years; but there is still a large number of $\frac{5}{8}$- and $\frac{3}{4}$-in. meters in service which have not been tested within this period. Formerly, meters removed from service for regular tests were tested at two points only: through a $\frac{1}{32}$-in. orifice for registration, and at full flow for percentage registration. Following cleaning and repairing, the same two-point test was repeated. There was no percentage requirement at the low flow, but at full flow a registration of 98 to 100 per cent. was necessary before the meter could be returned to service. At present, a four-point test is made, the $\frac{1}{32}$-in., $\frac{1}{16}$-in., $\frac{1}{4}$-in., and full-flow orifices being used. The $\frac{1}{16}$- and $\frac{1}{4}$-in. points were added as a result of the investigations made to determine the actual rates at which meters operate and the desirability of having a meter register accurately at these rates.

The Water Bureau has adopted the following registration requirements for repaired $\frac{5}{8}$- and $\frac{3}{4}$-in. meters as a result of the studies made on the draft of water through small meters:

Orifice. Inches.		Equivalent Flow. g.p.m.	Test Quantity. cu. ft.	Required Per Cent. Accuracy.
$\frac{1}{32}$		2/10	0	Must Register
$\frac{1}{16}$		7/10	1	93 or better
$\frac{1}{4}$		7–3/10	5	98–102
One size larger than meter	($\frac{5}{8}$)	18	10	98–102
	($\frac{3}{4}$)	21	10	98–102

As soon as the new testing procedure was employed, it was found that about 25 per cent. of repaired meters needed re-gearing, and that many of the older meters required new disks and chambers before they would meet the new test requirements. With so many meters requiring new disks and

TABLE 8.—UNRECORDED WATER AND RESULTING LOSS IN REVENUE IN HOUSES WITH TANK TOILETS—Based on registration tests of $\frac{5}{8}$- and $\frac{3}{4}$-in disk meters at the time of their removal from service for regular test.

Rate of Use of Water Gal. per Min.	% Registration.	SINGLE.			TWO-FAMILY.			THREE-FAMILY.		
		Assumed Quantity of Water Used.		Probable Amt. Recorded.	Assumed Quantity of Water Used.		Probable Amt. Recorded.	Assumed Quantity of Water Used.		Probable Amt. Recorded.
		Cu. Ft.	Gal.	Gal.	Cu. Ft.	Gal.	Gal.	Cu. Ft.	Gal.	Gal.
Less than $\frac{1}{2}$	70.0	1.8	13.5	9.5	3.9	29.2	20.4	10.3	77.0	53.9
$\frac{1}{2}$–1	88.	1.3	9.7	8.5	4.9	36.6	32.2	10.0	74.8	65.8
1–2	97.	1.3	9.7	9.4	7.1	53.1	51.5	11.4	85.3	82.7
2–3	98.8	0.4	3.0	3.0	2.5	18.7	18.5	4.2	31.4	31.0
3–4	98.8	2.4	18.0	17.8	5.2	38.9	38.5	2.0	15.0	14.9
4–5	99.0	1.4	10.5	10.4	2.6	19.5	19.4	1.3	9.7	9.6
5–10	99.3	2.8	20.9	20.8	2.3	17.2	17.1	1.2	9.0	8.9
25–30	99.3	....	....	....	....	....	....	....	....	....
Totals		11.4	85.3	79.4	28.5	213.2	197.6	40.4	302.2	266.8
Percentage total water recorded			93.1			92.7			88.3	
Unrecorded water per day—gal.			5.9			15.6			35.4	
Unrecorded water per year—gal.			2 153.			5 694.			12 921.	
Annual loss in revenue @ 20¢ per 1 000 gal.—$			0.43			1.14			2.58	

TABLE 9.—UNRECORDED WATER AND RESULTING LOSS IN REVENUE IN HOUSES WITH FLUSHOMETER TOILETS—Based on registration tests of ⅝- and ¾-in. disk meters at the time of their removal from service for regular test.

Rate of Use of Water Gal. per Min.	% Registration.	SINGLE.			TWO-FAMILY.			THREE-FAMILY.		
		Assumed Quantity of Water Used.		Probable Amt. Recorded.	Assumed Quantity of Water Used.		Probable Amt. Recorded.	Assumed Quantity of Water Used.		Probable Amt. Recorded.
		Cu. Ft.	Gal.	Gal.	Cu. Ft.	Gal.	Gal.	Cu. Ft.	Gal.	Gal.
Less than ½	70.	1.8	13.4	9.4	2.5	18.7	13.1	10.2	76.3	53.4
½–1	88.	2.0	15.0	13.2	1.0	7.5	6.6	10.2	76.3	67.1
1–2	97.	2.3	17.2	16.7	3.4	25.4	25.1	14.0	104.7	101.6
2–3	98.8	2.0	15.0	14.8	2.0	15.0	14.8	3.7	27.7	27.4
3–4	98.8	2.0	15.0	14.8	1.9	14.2	14.0	2.8	20.9	20.6
4–5	99.0	0.9	6.7	6.6	2.4	18.0	17.8	0.9	6.7	6.6
5–10	99.3	1.7	12.7	12.6	0.7	5.2	5.2	1.1	8.2	8.1
25–30	99.3	5.7	42.6	42.3	20.3	151.8	150.7	19.0	142.1	141.1
Totals		18.4	137.6	130.4	34.2	255.8	247.3	61.9	463.0	425.9
Percentage total water recorded				94.8			96.7			92.0
Unrecorded water per day—gal.				7.2			8.5			37.1
Unrecorded water per year—gal.				2 628.			3 102.			13 542.
Annual loss in revenue @ 20¢ per 1 000 gal.				—$ 0.53			0.62			2.70

chambers, the practice of fitting these parts at the shop was discontinued in favor of factory-fitted parts. This policy, in general, has produced satisfactory results, both as to the quality of the work and the cost of doing it. The new testing procedure consumes somewhat more time with a resulting increase in cost, but it is believed that the increase in revenue due to more accurate registration will more than offset the increased cost of testing, besides allowing for a better check on discrepancies between the master meter on the supply lines and the sum of the meters on consumers premises.

The dotted line in Figure 6 shows an average registration curve developed from a number of tests on repaired $\frac{5}{8}$- and $\frac{3}{4}$-in. meters, a summary of these tests being given in Table 10. By applying the percentage of registration indicated by the "repaired meter curve" (Fig. 6) to the amount of water used as given in Table 6, the percentage of unrecorded water and revenue loss per meter for houses equipped with tank toilets are obtained as shown in Table 11. They range from 2 to 3.5 per cent. for unregistered water, and from \$0.12 to \$0.80 per meter per year for loss in revenue. Corresponding figures for houses having flushometer toilets are given in Table 12 and show 1.6 to 2.8 per cent. unregistered water with revenue losses ranging from \$0.17 to \$0.90 per meter per year.

TABLE 10.—SUMMARY OF TESTS ON REPAIRED METERS.

No. of Meters Tested.	Average Age of Meters. (Yrs.)	PERCENTAGE REGISTRATION.			
		$\frac{1}{12}$-in.	$\frac{1}{16}$-in.	$\frac{1}{4}$-in.	Full Flow.
$\frac{5}{8}$-IN. METERS 28	21	Reg.	95.8	100.6	99.7
$\frac{3}{4}$-IN. METERS. 47	22	Reg.	96.9	100.7	99.6
Plotting points for $\frac{5}{8}$- and $\frac{3}{4}$-in. meters. (Fig. 6)			95.8	100.7	99.6

A comparison of the losses in revenue, based on tests on meters taken directly from service and on repaired meters, is given in Table 13 and indicates a reduction in revenue loss or reclamation of lost revenue, ranging from about 50 to 70 per cent. If applied to all $\frac{5}{8}$- and $\frac{3}{4}$-in. meters in service this would amount to a saving of over \$5 000 per year. It should be noted that this indicated saving results largely from higher registration on low flows rather than over-registration at the higher flows to balance the loss on low flows.

Tables 14 and 15 are submitted to show the condition of meters re-

TABLE 11.—UNRECORDED WATER AND RESULTING LOSS IN REVENUE IN HOUSES WITH TANK TOILETS—Based on registration tests of $\frac{5}{8}$- and $\frac{3}{4}$-in. disk meters removed from service, repaired and conditioned for return to service.

Rate of Use of Water Gal. per Min.	% Registration.	SINGLE.			TWO-FAMILY.			THREE-FAMILY.		
		Assumed Quantity of Water Used.		Probable Amt. Recorded.	Assumed Quantity of Water Used.		Probable Amt. Recorded.	Assumed Quantity of Water Used.		Probable Amt. Recorded.
		Cu. Ft.	Gal.	Gal.	Cu. Ft.	Gal.	Gal.	Cu. Ft.	Gal.	Gal.
Less than $\frac{1}{2}$	89.	1.8	13.5	12.0	3.9	29.2	26.0	10.3	77.0	68.5
$\frac{1}{2}$–1	97.4	1.3	9.7	9.4	4.9	36.6	35.6	10.0	74.8	72.9
1–2	99.2	1.3	9.7	9.6	7.1	53.1	52.7	11.4	85.3	84.6
2–3	100.0	0.4	3.0	3.0	2.5	18.7	18.7	4.2	31.4	31.4
3–4	100.4	2.4	18.0	18.1	5.2	38.9	39.0	2.0	15.0	15.1
4–5	100.4	1.4	10.5	10.5	2.6	19.5	19.6	1.3	9.7	9.7
5–10	100.4	2.8	20.9	21.0	2.3	17.2	17.3	1.2	9.0	9.0
25–30	100.3	....	....	....	....	.....	.....	....	.....	.....
Totals		11.4	85.3	83.6	28.5	213.2	208.9	40.4	302.2	291.2
Percentage total water recorded			98.0			98.0			96.4	
Unrecorded water per day—gal.			1.7			4.3			11.0	
Unrecorded water per year—gal.			620.			1 570.			4 015.	
Annual loss in revenue @ 20¢ per 1 000 gal.—$			0.12			0.31			0.80	

TABLE 12.—UNRECORDED WATER AND RESULTING LOSS IN REVENUE IN HOUSES WITH FLUSHOMETER TOILETS—Based on registration tests of $\frac{5}{8}$- and $\frac{3}{4}$-in. disk meters removed from service, repaired and conditioned for return to service.

Rate of Use of Water Gal. per Min.	% Registration.	SINGLE.			TWO-FAMILY.			THREE-FAMILY.		
		Assumed Quantity of Water Used.		Probable Amt. Recorded.	Assumed Quantity of Water Used.		Probable Amt. Recorded.	Assumed Quantity of Water Used.		Probable Amt. Recorded.
		Cu. Ft.	Gal.	Gal.	Cu. Ft.	Gal.	Gal.	Cu. Ft.	Gal.	Gal.
Less than $\frac{1}{2}$	89.	1.8	13.4	11.9	2.5	18.7	16.6	10.2	76.3	67.9
$\frac{1}{2}$–1	97.4	2.0	15.0	14.6	1.0	7.5	7.3	10.2	76.3	74.3
1–2	99.2	2.3	17.2	17.1	3.4	25.4	25.2	14.0	104.7	103.9
2–3	100.	2.0	15.0	15.0	2.0	15.0	15.0	3.7	27.7	27.7
3–4	100.4	2.0	15.0	15.1	1.9	14.2	14.3	2.8	20.9	21.0
4–5	100.4	0.9	6.7	6.7	2.4	18.0	18.1	0.9	6.7	6.7
5–10	100.3	1.7	12.7	12.7	0.7	5.2	5.2	1.1	8.2	8.2
25–30	98.8	5.7	42.6	42.1	20.3	151.8	150.0	19.0	142.1	140.4
Totals		18.4	137.6	135.2	34.2	255.8	251.7	61.9	463.0	449.9
Percentage total water recorded			98.2			98.4			97.2	
Unrecorded water per day—gal.			2.4			4.1			13.1	
Unrecorded water per year—gal.			876.			1 496.			4 781.	
Annual loss in revenue @ 20¢ per 1 000 gal.—$			0.17			0.30			0.96	

moved from service for regular test. These meters were selected at random and are probably typical of the other revenue-producing meters in service. From a study of these tables, it will be noted that a great majority of the meters have been in continuous service for more than five years, and that under-registration was so common a fault as to require replacement of the disk and chamber in seven out of every ten meters tested, before they could properly be returned to service. If the under-registration of these meters had been used in computing loss of revenue, the amount would have been much more than the $11 000 previously computed. The tables indicate forcefully the desirability of frequent and thorough tests of consumers' meters.

TABLE 13.—REDUCTION IN PERCENTAGE OF UNRECORDED WATER AND IN LOSS IN REVENUE.

TYPE OF HOUSE.	AS REMOVED FROM SERVICE PRIOR TO REPAIRING.		AFTER REPAIRING PRIOR TO RETURN TO SERVICE.		% Saving (4) over (2).
	% Water Unrecorded.	Annual Rev. Loss per Meter. $	% Water Unrecorded.	Annual Rev. Loss per Meter. $	
	(1)	(2)	(3)	(4)	
HOUSES WITH TANK TOILETS.					
Single	6.9	0.43	2.0	0.12	72.1
Two-Family	7.3	1.14	2.0	0.31	72.8
Three-Family	11.7	2.58	3.6	0.80	69.0
HOUSES WITH FLUSHOMETER TOILETS.					
Single	5.2	0.53	1.8	0.17	67.9
Two-Family	3.3	0.62	1.6	0.30	51.6
Three-Family	8.0	2.70	2.8	0.96	64.4

CONCLUSION.

The Hartford water system is typical of many other metered systems and conditions prevailing there are undoubtedly to be found elsewhere.

The investigations discussed in this paper indicate the importance to fully-metered water utilities of further studies along the following lines if meter registration and consequently income are to be kept at the maximum level consistent with equity between utility and consumer:

(1) Regular testing of all meters in service.
(2) A testing procedure with test points selected to cover the actual rates of flow at which meters ordinarily operate.
(3) A repair procedure which will insure that the measuring element of the meter is replaced before it becomes sufficiently worn to produce excessive under-registration at low flows.
(4) Proper sizing of the meter to adapt it to the service expected.
(5) Slightly higher accuracy requirements for the lower rates of flow in both new and repaired meters than obtain at present under the specifications of the Water Works Association.
(6) Revision of public utility specifications which permit under-registration at low rates without permitting reasonable over-registration at higher rates (New York State).

TABLE 14.—RECORDS OF ¾-IN. METERS IN SERVICE.

Letter.	Shop Number.	Year Bought.	Last Set (Set 0).			Removed.						Tests after Repairs.				Repair Costs.		
			Date.	Tests.		Date 1932.	Water Passed. Cu. Ft.	Tests.								Labor.	Disk and Chamb.	Other Matl.
				1/2	F.F.			1/2	1/4	F.F.		1/2	1/4	3/4	F.F.			
W.D.	767 955	1922	5/28/23	99.2	100.0	June 2	150 568	Inter. broken				R.	102.0	102.0	101.0	.49	4.00	2.15
T.	139 540	1902	2/3/19	reg.	99.5	Aug. 3	120 424	Piston out of order				R.	98.0	99.6	98.0	.43	4.20	2.46
H.	686 198	1916	9/30/16	99.2	99.8	Aug. 3	118 437	Inter. broken				R.	94.0	100.0	99.0	.50	5.29	2.81
W.D.	767 952	1922	5/26/23	94.7	100.0	June 6	117 894	N.R.	R.	102.3		R.	.....	101.5	100.8	.61	....	2.15
W.D.	620 115	1921	5/31/21	90.6	100.0	June 4	112 565	Inter. broken				R.	99.0	99.4	98.0	.74	....	2.15
W.D.	767 862	1922	4/19/23	96.1	100.0	June 8	111 179	R.	....	101.5		R.	80.0	101.8	101.0	.37	....	.08
L.	174 094	1900	9/23/19	R.	98.0	June 23	102 094	Does not R.		91.8		R.	99.0	100.8	99.9	.28	2.37	3.66
H.	644 290	1916	4/17/16	94.7	100.0	July 15	101 059	Plugged by dirt				R.	100.0	100.6	100.2	.35	5.29	.56
L.	182 364	1901	1/20/10	R.	99.8	July 15	98 485	R.	30.0	98.7		R.	100.0	101.8	101.0	.60	2.37	.94
L.	182 362	1901	No record.			July 12	96 002	N.R.	38.0	94.4		R.	94.0	99.6	99.2	.35	2.37	.96
W.	978 138	1924	7/21/24	94.7	98.0	July 1	92 234	R.	....	100.8		R.	.....	101.0	99.5	.82	....	.37
T.	77 405	1900	3/21/28	R.	98.6	July 15	90 065	R.	25.0	103.8		R.	99.0	99.6	98.8	.25	4.20	.53
H.	1 230 476	1927	4/16/27	99.2	100.8	July 27	83 145	R.	70.0	101.3		R.	100.0	99.8	99.0	.32	5.29	.20
T.	84 753	1900	2/9/24	R.	98.6	June 27	81 401	R.	No record.	99.8		R.	90.0	101.0	101.0	.37	....	2.46
W.	977 947	1923	12/11/23	99.2	98.9	June 30	80 541	R.	....	100.8		R.	90.0	99.2	98.0	.48	....	.36
W.D.	767 939	1922	12/2/27	R.	98.0	June 22	76 865	R.	....	100.0		R.	.....	102.0	100.8	.61	....	.08
W.	977 878	1923	10/1/23	97.6	100.0	July 1	76 277	Inter. broken				R.	98.0	102.0	100.2	1.31	4.50	.06
H.	679 392	1916	10/8/26	R.	99.5	Aug. 4	74 397	Piston out of order				R.	102.0	102.0	101.5	.28	5.29	.20
L.	169 127	1900	10/3/19	R.	98.4	July 28	72 566	N.R.	N.R.	98.6		R.	90.0	98.0	98.0	.24	2.37	3.64
T.	77 390	1900	6/24/25	R.	98.0	July 19	64 930	Does not reg.		101.2		R.	98.0	99.2	98.0	.56	4.20	2.44
L.	182 374	1901	4/30/24	R.	100.0	July 15	64 188	R.	46.0	102.4		R.	90.0	100.4	100.8	.86	2.37	.08
L.	181 222	1901	No record.			July 11	59 921	R.	11.0	92.0		R.	97.0	100.0	98.2	.35	2.37	.16
W.	977 897	1923	2/25/27	R.	98.4	July 1	58 274	R.	....	97.0		R.	.....	101.0	99.9	.69	....	1.00
L.	182 336	1901	3/12/20	R.	98.0	July 11	56 093	R.	41.0	98.4		R.	98.0	101.0	100.5	.44	2.37	.96
T.	89 244	1901	1/10/23	R.	99.2	July 21	55 428	Does not reg.		102.0		R.	98.0	99.8	99.2	.56	4.20	2.96
T.	77 294	1900	3/9/27	R.	98.4	June 27	55 047	R.	No record.	100.5		R.	93.0	103.0	102.0	.37	....	2.46

R.—Registers.
N.R.—Does not register.

TABLE 14.—RECORDS OF ⅝-IN. METERS IN SERVICE.—*Continued.*

Letter.	Shop Number.	Year Bought.	Last Set (Set 0).			Removed.					Tests after Repairs.				Repair Costs.		
			Date.	Tests.		Date 1932.	Water Passed. Cu. Ft.	Tests.							Labor.	Disk and Chamb.	Other Matl.
				⅛	F.F.			⅛	¼	F.F.	⅛	¼	½	F.F.			
T.	417 837		No record.			July 28	51 709	R.	38.0	95.4	R.	93.0	100.0	99.0	.37	4.20	2.79
W.D.	767 856	1922	4/17/23	93.3	99.7	June 1	51 682	..	R.	R.	R.	98.0	101.8	100.3	.49	4.00	2.15
W.	727 844	1917	8/28/24	R.	100.0	July 9	40 701	R.	No record.	101.2	R.	97.0	99.6	98.3	.50	4.50	8.00
W.	978 087	1924	6/12/24	93.3	99.2	July 22	36 024	R.	95.0	101.0	R.	92.0	100.5	99.0	.55	....	.06
L.	180 661	1901	1/9/30	70.0	99.8	July 16	35 437	N.R.	23.0	100.2	R.	98.0	98.5	101.5	.74	2.37	2.45
T.	87 177	1901	3/1/29	R.	98.0	Aug. 1	34 295	N.R.	N.R.	100.5	R.	90.0	99.6	98.8	.25	4.20	6.58
T.	84 681	1900	8/1/28	R.	98.3	July 12	33 281		Plugged.		R.	100.0	101.8	101.0	.82	....	.05
T.	84 180	1900	5/12/26	R.	98.0	June 29	33 060	N.R.	R.	98.1	R.	93.0	101.2	100.3	.37	....	2.43
W.	905 425	1921	11/30/26	R.	98.0	July 5	32 961	R.	No record.	20.0	R.	98.0	101.6	101.1	.69	....	.50
L.	473 921		No meter record.			June 6	30 830	N.R.	R.	96.0	R.	92.0	101.0	100.8	.31	2.37	2.53
T.	77 481	1900	9/8/27	R.	98.1	June 29	28 511	N.R.	R.	98.0	R.	92.0	101.8	100.2	.61	....	2.38
T.	85 956	1901	12/20/26	R.	99.2	July 25	27 574	R.	80.0	101.4	R.	97.0	99.4	98.6	.24	4.20	4.33
L.	509 111		No meter record.			July 11	26 349	R.	42.0	98.3	R.	92.0	99.6	98.8	.24	2.37	3.43

R.—Registers.
N.R.—Does not register.

TABLE 15.—RECORDS OF ¾-IN. METERS IN SERVICE.

Letter.	Shop Number.	Year Bought.	Last Set (Set 0).			Removed.					Tests after Repairs.				Repair Costs.		
			Date.	Tests.		Date 1932.	Water Passed. Cu. Ft.	Tests.							Labor.	Disk and Chamb.	Other Parts.
				1/12	F.F.			1/12	1/6	F.F.	1/12	1/6	1/4	F.F.			
H.	1 169 325	1926	7/29/26	90.6	99.5	June 15	920 500	R.	80.0	102.8	R.	93.0	101.0	100.3	.61	....	4.97
L.	169 154	1900	11/22/21	R.	99.1	May 29	579 861	R.	No record.	100.4	R.	100.0	101.8	101.0	.37	4.64	7.48
L.	172 441	1900	9/28/23	R.	98.0	July 11	556 251	R.	60.0	101.2	R.	95.0	100.4	100.2	.50	4.64	4.91
T.	81 497	1900	3/11/19	R.	98.9	July 6	537 635	N.R.	R.	103.0	R.	90.0	99.9	99.0	.82	....	2.41
T.	320 631	1906	7/31/24	R.	98.0	July 16	486 402	N.R.	22.0	102.3	R.	99.0	100.6	98.8	.25	2.89	5.38
L.	175 348	1901	1/21/10	R.	99.8	July 12	450 530	N.R.	27.0	95.7	R.	99.0	99.2	98.8	.49	4.64	8.22
H.	711 980	1917	10/5/17	99.2	98.1	July 14	419 369	N.R.	86.0	97.0	R.	97.0	100.0	99.7	.74	6.64	11.17
T.	83 811	1900	5/21/18	R.	99.8	Aug. 5	365 570	Piston out of order			R.	99.0	102.4	100.8	.29	2.89	5.38
T.	86 295	1901	3/12/20	R.	98.0	July 18	359 476	N.R.	10.0	100.7	R.	100.0	102.0	100.7	.56	2.89	5.30
H.	711 985	1917	11/16/17	99.2	99.4	July 12	353 716	R.	92.0	98.1	R.	96.0	100.0	98.5	.56	....	6.93
T.	158 420	1904	No meter record.			July 12	353 700	R.	63.0	95.3	R.	99.0	102.0	100.2	.35	2.89	6.41
T.	200 835	1904	No meter record.			July 12	301 099	R.	88.0	98.3	R.	100.0	102.0	100.8	.74	2.89	7.09
L.	400 643	1909	9/30/19	R.	99.1	July 1	269 657	R.	No record.	96.2	R.	98.0	99.1	98.0	.92	4.64	4.78
H.	261 408	1906	2/18/21	R.	98.9	July 16	253 017	R.	100.0	100.8	R.	100.0	100.6	99.2	.29	6.64	9.44
L.	147 567	1900	3/15/18	R.	99.5	July 6	229 838	R.	No record.	99.8	R.	93.0	100.0	98.0	.28	4.64	5.60
T.	94 246	1901	5/21/26	R.	98.8	July 16	223 700	R.	40.0	98.7	R.	98.0	101.0	100.0	.56	2.89	5.36
H.	635 089	1915	6/21/21	R.	98.4	July 2	214 802	N.R.	½R.	96.0	R.	99.0	98.8	98.0	.50	6.64	9.30
W.	978 461	1923	11/13/23	90.6	99.5	July 14	200 273	R.	102.0	103.5	R.	93.0	101.2	100.8	.44	....	.08
H.	252 847	1906	2/16/21	R.	99.4	July 16	155 830	R.	86.0	101.8	R.	97.0	101.0	100.0	.42	6.64	9.42
H.	576 307	1914	11/5/14	99.2	100.0	July 12	141 530	R.	94.0	98.0	R.	97.0	99.0	99.2	.74	....	2.13
T.	3 576 696	1927	12/29/27	99.2	101.6	July 15	112 922	R.	92.0	101.2	R.	97.0	100.8	100.2	.69	....	.08
T.	200 833	1904	4/11/27	R.	98.9	July 21	112 164	Piston warped.			R.	98.0	100.4	99.5	.74	2.89	7.09

R.—Registers.
N.R.—Does not register.

TABLE 15.—RECORDS OF ¾-IN. METERS IN SERVICE.—*Continued.*

Letter.	Shop Number.	Year Bought.	Last Set (Set 0).			Removed.					Tests after Repairs.				Repair Costs.		
			Date.	Tests.		Date 1932.	Water Passed. Cu. Ft.	Tests.							Labor.	Disk and Chamb.	Other Part
				⅛	F.F.			⅛	¼	F.F.	⅛	¼	½	F.F.			
L.	556 162	1912	No meter record.			June 30	92 211	R.	No record.	101.0	R.	99.0	100.8	99.8	.44	4.64	8.22
L.	556 163	1912	No meter record.			June 30	77 946	N.R.	R.	93.3	R.	92.0	102.0	100.8	.50	4.64	9.50
T.	87 899	1901	6/7/26	R.	98.0	July 16	57 750	R.	82.0	98.0	R.	93.0	101.6	99.8	.29	2.89	5.38
T.	147 385	1904	5/14/29	R.	98.6	July 11	45 067	R.	100.0	100.8	R.	100.0	100.0	99.2	.74	....	2.41
T.	2 950 290	1925	5/7/25	97.6	99.2	July 9	40 672	R.	102.0	102.0	R.	100.0	99.8	99.2	.56	....	.08
W.	1 183 175	1926	10/21/26	94.7	98.4	July 28	38 440	Inter. broken.			R.	98.0	99.8	99.2	.87	....	.17
W.	1 217 968	1927	7/7/31	91.9	99.4	July 18	33 086	R.	98.0	102.0	R.	95.0	102.0	101.0	.56	....	.08
T.	412 314	1907	12/10/29	60.0	98.6	Aug. 4	25 302	Bottom casing broken.			R.	99.0	100.4	98.7	.36	....	3.04

R.—Registers.
N.R.—Does not register.

POWDERED ACTIVATED CARBON IN WATER PURIFICATION.

BY F. E. STUART.*

Unlike most chemicals used in routine water purification, activated carbon, being insoluble, removes tastes without contributing other tastes and without adding to the water substances other than itself. When its work is done it is completely removed along with the absorbed impurities. None of it passes on to the consumer.

In the early experiments with activated carbon in water purification granular carbon was employed. It was found, however, that the successful application of carbon in granular form was possible only with the aid of special and expensive equipment as well as costly changes in filter-plant design. With the introduction of powdered activated carbon to the water-works field, it was soon shown that the use of activated carbon was no longer a difficult problem. Experiments conducted with powdered activated carbon by numerous water-works' operators quickly eliminated the existing arguments against the use of activated carbon in water purification.

During the two years, 1931 and 1932, powdered activated carbon has grown in use to a remarkable degree until an appreciable number of water-treatment plants now employ it regularly in their treatment process. Although the primary reason for the application of activated carbon in water purification is to eliminate objectionable tastes and odors, there are additional advantages as well.

History of Carbon in Water Purification. For generations wood charcoal has been a household remedy in the purification and sweetening of water stored in cisterns. It is a known fact that the value of charcoal in water purification was recognized as early as 1807. Interestingly enough gold prospectors of Australia years ago added their campfire ashes, containing bits of charcoal, to contaminated or stagnant waters in order to purify them.

In America, the early pressure-filter installation at Atlanta, Ga., employed a mixture of sand and granular charcoal collected from the cinder traps on wood-burning locomotives. This was in 1893 and is believed to represent the earliest use of charcoal in water filtration in America, if not in the world. In England, about 19 years ago, activated carbon was used for the first time in pressure-type filters primarily for the purpose of removing chlorinous and other tastes from chlorinated water. Activated carbon was produced by the Industrial Chemical Sales Company in America as early as 1914, but it was not used to any practical extent in water purification until 1929. Pioneer work with granular activated carbon was undertaken in 1928 by John R. Baylis, in the experimental filter plant of Chicago,

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Ill. As a result one or two plants have been equipped with activated-carbon contact-filters.

Realization that the use of granular carbon was proving prohibitively expensive, because of the high first cost of installing the contact unit, led to experimentation with powdered activated carbon applied to the water ahead of sand filters. Credit for the pioneer efforts leading to the practical application and economical use of powdered activated carbon as a taste remover must be given to George R. Spalding at the New Milford, N. J. Filter Plant of the Hackensack Water Company. Spalding first applied powdered activated carbon on a plant scale in the spring of 1930. Since then its use has increased with rapid strides and through a variety of procedures.

The Role of Powdered Activated Carbon in Water Purification. The powdered activated carbon used in water purification is very fine and of exceptionally low density. It weighs 16 lb. per cu. ft., and 94 per cent. of its weight passes through a 200-mesh screen. Its fine particle size and great porosity offer an enormous exterior and interior surface, its low density insuring that it remains in contact with the water for long periods of time before it settles out. It is while in suspension that the carbon gets in its most effective work.

Odors and tastes in water are derived largely from organic matter and gases in the water. These are quickly absorbed by activated carbon to be removed along with the carbon during the process of sedimentation and filtration. The taste-producing substances may be derived from decomposing organic matter and from algæ or from industrial pollution of a stream.

Aside from removing tastes and odors, the application of powdered activated carbon to water ahead of, or along with, the coagulant at filtration works has proved advantageous also as follows:

(1). The large number of small particles in suspension stimulates rapid and effective floc formation, i.e. clotting of the turbidity or coloring matter normally present in surface waters. In softening processes the same phenomenon is noticed in conjunction with formation of insoluble calcium and magnesium compounds. In each case the rapidity of separation of precipitated impurities is facilitated by the presence of the carbon in suspension. Thus less suspended matter remains to be removed on the sand filters. The economical aspect of this effect is found in the need of less water for washing filters and, perhaps more important, in the reduction of the quantity of coagulant required. Where alkalinity must be added to improve floc formation, the use of powdered carbon reduces the drop in alkalinity in addition to the amount of coagulant required.

(2). The flocculated material settling out of the coagulated water carries much of the carbon with it. The resultant sludge, to a very marked extent, is prevented from decomposing. This serves as a secondary but important measure of preventing taste production during passage of *new* water across deposits of *old* sludge. The result is an operating economy. Less water is wasted in emptying and washing the basins which is ordinarily done quite frequently when tastes due to sludge are to be avoided. Tastes imparted to otherwise tasteless water by the decomposition of sludge in settling basins are more prevalent than heretofore realized.

(3). The use of powdered activated carbon serves to reduce the chlorine demand of water because colloidal and soluble organic matter and gases of decomposition are absorbed and removed. The chlorine demand of carbon-treated water becomes practically a constant value. Not alone does this reduce chlorine consumption, but it renders more certain the adequacy of uniform application of chlorine to filtered water. The necessity of frequent changes in rate of chlorination to meet varying water qualities is reduced.

(4). In connection with prechlorination the same phenomenon is noticed as described under (3). Strangely enough, the residual chlorine in passing through the basins to the filters is held at a more nearly constant figure than is observed when carbon is not applied. The presence of carbon in low concentration, such as is used in water purification practice, does not dechlorinate the water during passage through the basins. Passing through the filter, on which a portion of the non-settling carbon is deposited, complete dechlorination is effected and the effluent exhibits no chlorine demand. Thus, the chlorine dosage after filtration is practically all made available as residual chlorine. In consequence a dosage of constant amount can be depended upon.

(5). Chlorine present in water in a rapidly oxidizing form, such as free chlorine, hypochlorous acid or hypochlorite, is completely removed during passage through filters in or on which carbon has been deposited. Chlorine in the mildly oxidizing state (when present as mono and dichloramine) will only be partially removed during the filtration. In taste removal with activated carbon it appears to be questionable practice to employ the ammonia-chlorine process for prechlorination. Most dependable results are secured from the use of chlorine by itself in sufficient quantities to insure the presence of residual chlorine on top of the filters . Complete dechlorination should take place during passage through the filters. If desirable to maintain a chlorine residual through the distribution system, ammonia may be used in conjunction with final chlorination. In this way it becomes possible also to maintain the desired concentration of available chlorine in the finished water without production of chlorinous tastes in the already chlorine-saturated water.

Methods and Technique of Powdered Carbon Application. In general there are two proved methods for applying powdered activated carbon to water. In either case the powder is added to a minor flow of water which suspends the dry material before it is admitted to the major flow of water to be treated. The equipment involved may be:

(a) An ordinary chemical dry-feeder equipped with a solutionizing box or a water-operated ejector.
(b) A solution tank provided with continuous mechanical or compressed-air agitation.

In the early use of powdered carbon it was applied directly to the water entering the filters. This practice is being continued at several plants where the quantities of carbon required do not exceed 16 lb. per m.g. (2 p.p.m.). This scheme has proved most effective when prechlorination is employed and offers the most immediate relief in cases where unexpected odors or tastes are encountered. The procedure can be used in emergencies or for

short periods of time even with the knowledge that filter runs may be shortened when the carbon dosage is more than 16 lb. per m.g.

A procedure which has shown itself to be more attractive, both from the standpoint of overall taste control and the previously mentioned incidental benefits and economies, consists in adding a carbon suspension to the raw water ahead of the coagulation basin, along with the coagulant or after addition of the coagulant. In conjunction with prechlorination the carbon may be applied prior to or subsequent to the chlorine. Usually the overall results have been better when the carbon has preceded the chlorine. In this case, higher residuals of chlorine usually result with equal chlorine dosage. Circumstances may alter the case, and the preferable arrangement should be determined by tests. Where taste troubles are exceptionally severe a combination of prechlorination with pre-carbon treatment and additional carbon treatment ahead of the filters may solve the problem. Some of the worst conditions encountered in the field have been remedied by splitting application of carbon between the raw water and the water applied to the filters.

Carbon Dosage Involved. Generally, the quantity of powdered carbon requisite for proper taste control has been found to lie between 8 and 24 lb. per m.g. (1 to 3 p.p.m.). In exceptional cases dual application of the carbon has been required, and a total dosage in excess of these values has been necessary. The amount of carbon that must be applied to raw water is generally higher than the amount required when the carbon is applied at the filters. The advantages previously named, together with the saving in coagulant and chlorine, more than compensate, however, for the slightly higher dosages required when carbon is used in conjunction with coagulation.

Acknowledgment. The writer wishes to acknowledge the many helpful suggestions he has obtained from Mr. L. H. Enslow, Engineer, The Chlorine Institute and Editor of *Water Works and Sewerage*, in connection with the application of powdered activated carbon in water treatment.

PROCEEDINGS.

WATER WORKS SCHOOL DINNER.

WALKER MEMORIAL, CAMBRIDGE.

Friday, June 10, 1932.

*Extracts from Remarks by William F. Sullivan.**

Mr. Robert Spurr Weston, Chairman of the Committee on Educational Service of the NEW ENGLAND WATER WORKS ASSOCIATION invited me to this first dinner of the Water Works School to tell you youngsters something about the old timers in the water-works field. I assume he thought it was the right of the second generation of oldsters to indulge in reminiscence. He himself has a rating in this class and I wish he were with us so that he might add his meed of praise due the organizers of this Association.

I belong to the group which joined the Association in the late nineties, and being of the first line of succession had the pleasure and the privilege of meeting and hearing many of the founders of this organization tell their experiences, and I profited by their advice. Sometimes it was necessary to repress the enthusiasm of the youngsters who thought they were wiser than Dad. The "Old Guard" were real pioneers in community service. Often in a day's work they found themselves in a difficult spot, but they pulled out of it by sheer Yankee ingenuity and natural ability. They were real builders and developers with much engineering talent but in most cases without technical training. Fifty years ago almost to a day this group builded well when they started this organization which was destined to fill a long-felt want. These sturdy men rose to the positions of superintendents, station engineers and executives from machine shop, from counting room and even from the trench by sheer force of character. A few rose by the political route, but all had "it" with merit. They were unafraid of hard work and long hours. They had tough, uncharted undertakings to perform. Entrusted with responsibilities greater than those in any other municipal department, these men were tested in heat and cold and took it wet or dry in and out of season. To arrive at the position of administrative heads the old timers usually passed through the grades of worker, foreman, office man or rodman. They displayed keen mechanical knowledge in difficult operations and were born leaders of men, with sympathy and loyalty to their subordinates. In addition they had the good will and confidence of the public. No matter what his "alma mater" the early water-works man was straightforward, two-fisted, hard hitting, reliable and of unquestioned honor and integrity.

*President, Pennichuck Water Works, Nashua, N. H.

This Association gave these pioneers the opportunity to band together for friendly intercourse and mutual aid. This Association was the vehicle which carried many of them far in their life's work. Their endeavor was utilitarian and commercial, that is, to serve a community with a needed commodity. While the cost of plant and service was high they were charged with the duty of keeping the rates reasonably low.

A few years from its inception our fraternity had developed into a semi-scientific organization. This was brought about by the accumulated fund of knowledge and experience acquired over years of application to the work of supplying water. These men were sound reasoners, keen parliamentarians and possessors of technical knowledge worthy to be printed and recorded in the JOURNAL for use by the later generations of water-works men. Trained engineers, chemists and bacteriologists soon recognized the advantages of linking the scientific with the practical, and no one can say that this has not been a happy alliance. The Charter members fully realized the need of the practical and the scientific minded to work together on the ever-expanding problems of better and safer water supplies.

In the early days water was just H_2O but with many an old water-works man it was all right so long as it was fairly clear and reasonably free from color and odor. The slogan "Water — God's best gift to Man" was invented. That was satisfactory so long as the water was free from qualities which increased the mortality rate. It took a few of the old timers quite a while to become quality conscious and realize that contamination of certain kinds produced sickness and death.

It was not until communities grew and the uses of water multiplied and shortage followed that the people in cities sensed that the great gift was not "as free as air." Pure and undefiled air is not always free unless you go where it is to be found. Often it was an effort for an old timer to convince a part of his community of the meaning of water service with its manifold parts and operations, and much time and effort was often spent before a good citizen believed a reasonable water charge was just. Why shouldn't they kick, isn't water found free in Nature? It took much argument to prove that this statement is not true, especially when water is under pressure and may be had by the turn of the wrist.

Forty and fifty years ago when water works had been established for only a few years, increases in population called for more water which often meant new supplies. Here again the Association fitted in. The knowledge acquired at meetings enabled the water-works men to sell the idea to the communities. The Grand Old Men were on deck to lead the great prospecting for many a growing city. In many places which did not have running water there was a demand for this kind of enterprise, which when completed would release many from drudgery and furnish fire protection. The prospect at first was hailed with delight by the inhabitants, but the citizens who paid the bills had to be convinced. This was usually accomplished, in part, by the confidence and faith they had in the old-time water-works

man who could qualify as an expert. They were not mistaken in trusting these wise "old fellows" and were rewarded by getting a service which not only produced happiness but dividends in safety and dollars. The pioneers had real vision when they founded this Association for social intercourse and for exchange of ideas.

You of a later generation, too, must have had a liking for this high type of service. The task is heavy, for water-works operation covers twenty-four hours a day the year around. It is a reflection on the management to have an interruption even for a short time, and the heart of many a water-works man has beaten faster until a situation of this kind was rectified.

How did the old leaguers begin a lifetime of activity and responsibility? How did you young men get onto the water wagon? It must be that you and they were just natural service men, or was the incentive derived from seeing a great work in progress or were you inspired by the life of some greater engineer or builder?

This Association has always been rich in men. Look over the past files of the JOURNAL and you will find a long list of eminent men who left a heritage of information hard to obtain anywhere else.

In olden days the Convention was a great institution. The supply men captured the "boys" during the recesses and it was "water, water everywhere, but not a drop to drink." Those were days when the members added to their fund of knowledge, listened to good stories and had a good time in general. This portion of the convention program added a bit of color and good fellowship to the proceedings.

Your job today is easier than "Dad's." Automobiles in place of "old Dobbin" with labor-saving devices of all kinds. Now you have to contend with the "bug" of efficiency which has produced an epidemic of unemployment and misery. Air has replaced picks. Many substitutes have been introduced since the old man's time such as those which take the place of lead joints and lead pipe. Scientific forestry now plays a part in water conservation where formerly it was just woodland.

You young men are indeed fortunate to have had a week's intensive training under the most favorable conditions, here in Cambridge, instructed by teachers from Harvard and Technology. You have been fortunate to have such men of learning devote their time to you so that you may go back to your job with a better knowledge of your work and its responsibilities. The men in the Association who promoted this school are entitled to much praise, and this first class from the New England Water Works school fully warrants its establishment. Water-works management now is a combination of art and science and your diploma entitles you to be a marked man in your organization. This school should be continued, and water departments and companies should recognise it and should send water-works students to it at no expense to them. The knowledge gained

here by the student will be of greater value to the system in which he is employed than to the student himself.

In closing let me quote from the address of past President George H. Finneran — "Let us remember those sturdy characters that built this Association fifty years ago. Let us try to put into our work the same earnestness and determination to overcome obstacles that they did. Let us hold to their lofty ideals and purposes, and if possible, advance from where they left off."

GEORGE ALFRED KING.

George Alfred King, of Taunton, son of George Pickens and Mary Leonard (Kinnicutt) King, was born at Taunton on May 25, 1856, and died in Boston, after a brief illness, on April 26, 1932.

He was a descendant in the eighth generation of Philip King, a native of Northam, County Devon, England, an emigrant to Braintree before 1680, whose wife was Judith Whitman. His mother, Mary Leonard Kinnicutt, was born in Taunton, the daughter of Benjamin Townsend and Eliza (Dean) Kinnicutt.

Mr. King attended the public schools of Taunton and entered the Lawrence Scientific School in 1873, but left at the end of his first year to take up the professional work which he followed until the end of an active and serviceable life. He was very successful in this field and had charge of many important engineering works in and near Taunton, supervising the construction of the Lakeville addition to the Taunton water-supply system, the laying-out of several street-railway lines and the erection of many bridges.

He also served Taunton in many capacities; assessor of taxes from 1889 to 1893, city engineer in 1894 and from 1898 to 1903, superintendent and clerk of the water works from 1903 until his death.

When a young man he enlisted in Company F, Massachusetts Volunteer Militia, and rose to the rank of Captain.

Mr. King became a member of the New England Water Works Association in 1903 and was its President in 1910. He was also a member of the Boston Society of Civil Engineers from 1888, the Harvard Club of Boston, the Old Colony Historical Society, the Massachusetts Society of Colonial Wars, the Governor and Company of the Massachusetts Bay Colony, and a founder of the Massachusetts Assessors Association.

He was a trustee of the East Taunton Congregational Church for nearly thirty years and had been chairman of the standing committee of the Winslow Congregational Church since 1909.

Mr. King was greatly interested in the work of the New England Historical Genealogical Society, to which he gave much of his time and interest since his election to membership in 1914, serving as a Councillor, 1924 to 1927 and Chairman of the Committee on Epitaphs and Records from 1927 until his death, in which positions he rendered efficient service.

He married on April 25, 1880, Florence Wales Dean, daughter of John Wales and Catherine Rebecca (Blandin) Dean who died two months before her husband. Their two children, Lucy Catherine and Arthur Caswell

King, survive, the last named succeeding his father as superintendent and clerk of the water works.

Mr. King was a genial, dignified Christian gentleman in every sense of the word, and his memory will be cherished by all who were favored with acquaintance or association, which was the good fortune of the writer for more than thirty years.

JOHN CARROLL CHASE.

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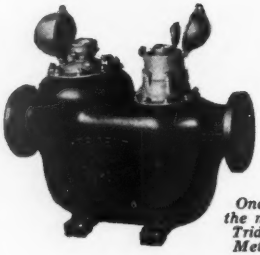

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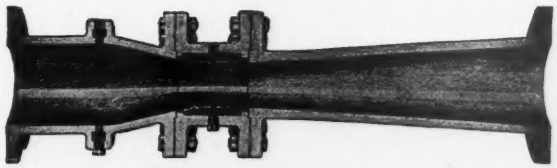

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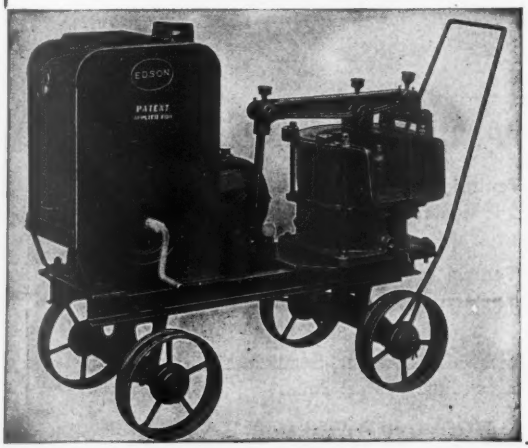

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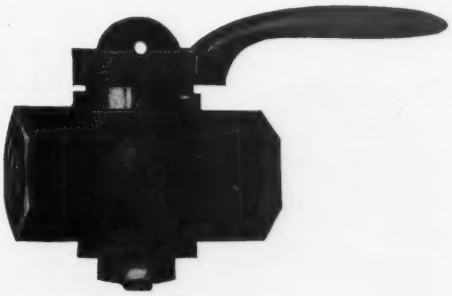

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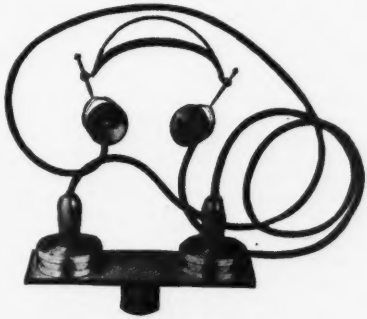

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Lead Pipe, Tin Lined Lead Pipe, Pure Block-Tin Pipe, Solder, White Lead and Red Lead.

HIGHEST QUALITY SOFT BRANDS

PIG LEAD

CLEAN PIPE LINES

having high coefficients deliver more water and give better fire protection than corroded mains.

High coefficients mean greater delivery in gravity mains and lower power costs in pumping mains.

GENERAL PIPE CLEANING COMPANY

Commercial Trust Bldg. Philadelphia, Pa.

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WATER PUMPING INSTALLATIONS
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All Types of Pumps in Stock for Rental

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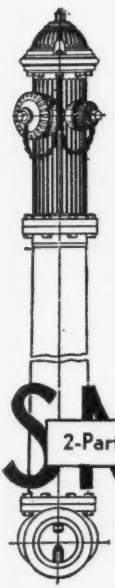


WHEN HYDRANTS ARE APT TO BE BUMPED

WHERE exposed locations subject hydrants to the jolts and bumps of traffic, our New York Standard Hydrant with Two-Part Standpipe offers sure protection. It has been on the market eight years.

Whether broken above or below its flange, repair is quick and easy. And in no circumstance will it allow water from the main to flow. Its main valve will close with the pressure, even if the latter is small. Water cannot flood streets.

SMITH

2-Part Standpipe Hydrant

THE A. P. SMITH MFG. CO.,
East Orange, N. J.

YOUR DOLLAR'S WORTH IN A METER SETTING!

It is just as much false economy to set a water meter in the cheapest way as it is to do the plumbing of a house in the cheapest way—

A water meter set in a Ford Yoke or in a Copperhorn Meter Coupling can be easily removed and replaced without disturbing the service pipe—

This one fact alone justifies what slight extra cost there may be—

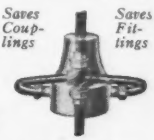
THE FORD METER BOX CO.
Wabash, Ind.

Water Meter Setting and Testing Equipment

Ford Yoke for Setting on Risers

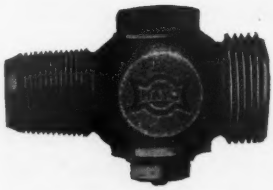
Straight Line Yokes for shallow meter box or basement settings in horizontal piping

Saves Couplings *Saves Fittings*

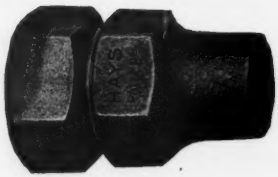


Ford Copperhorn Meter Coupling

The Hays Copper Plumbing Method



Regular Corporation Stop

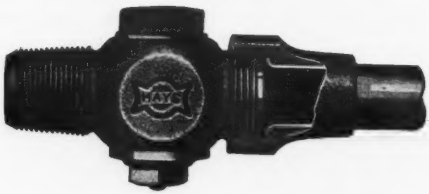


Adapter

In making an installation with Hays Copper Service Fittings the regular Corporation Stops can be used in conjunction with the adapter. It is not necessary to procure new mandrels, as the Corporation Stops are inserted with the regular mandrels, in the usual manner, after which the adapter is attached.

Open View of Adapter

These adapters are made with Female Thread for Increased I. P., Water Works Standard or Lead Flange.

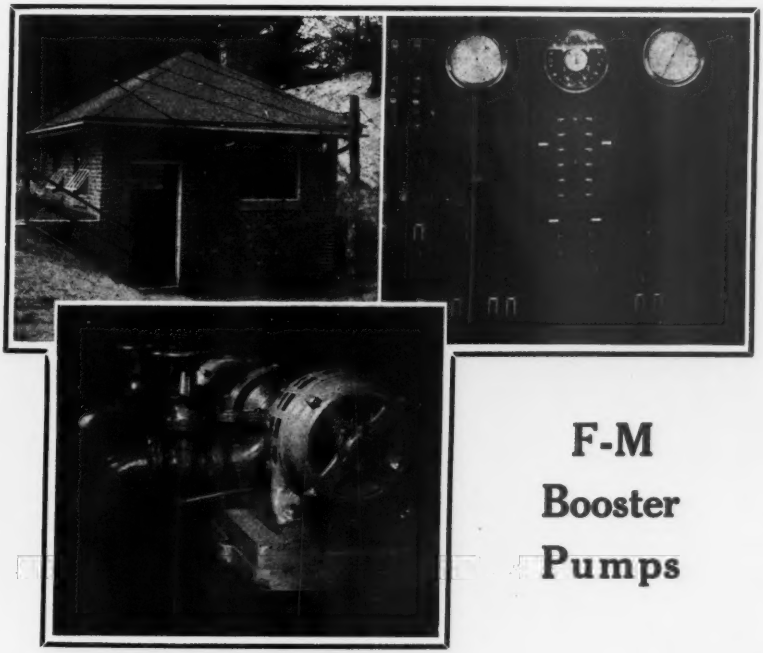


To use standard Corporation Stops with Increased I. P. or Water Works Standard Thread, and where a direct connection of the Corporation Stop and Copper Pipe is desired, the above stop has been designed. (See cut above for sectional view of joint.) These stops permit a Hays 90° seal with the use of regular male mandrels.

Write for complete details of

The Hays Copper Plumbing Method for Water Works and House Plumbing

Hays Manufacturing Co. Erie, Pa.



F-M Booster Pumps

At SOUTH HADLEY, MASS.

Shown above are the exterior of the South Hadley Water Works Pumping Station, the two F-M Motor Driven Centrifugal Pumps installed in the station and the control equipment. The station is located at one extreme end of the town and takes water from a small reservoir under a positive head of approximately 12 or 15 feet and pumps it through the main section of the town to a standpipe at the other end. Both pumps and motors are of ball bearing design, which construction was selected because of the desirable feature of lubrication. The bearings require attention only once a year.

FAIRBANKS, MORSE & CO.

178 Atlantic Avenue, Boston, Mass.

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PUMPS · DIESEL ENGINES · MOTORS

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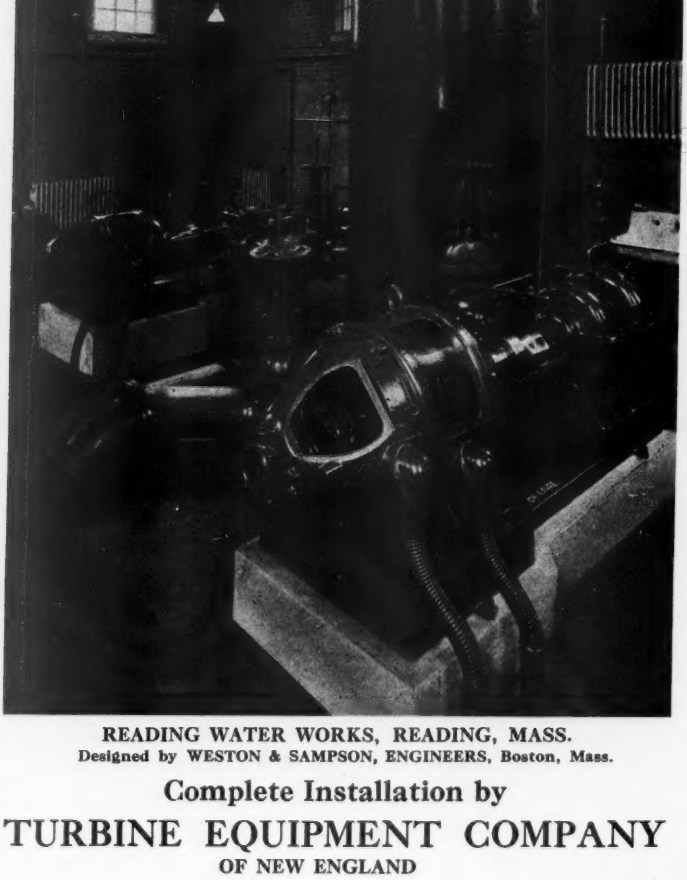
Operating on Driven Wells

Continuous Vacuum Priming System insures safety of operation without operator in attendance.



READING WATER WORKS, READING, MASS.
Designed by WESTON & SAMPSON, ENGINEERS, Boston, Mass.

Complete Installation by

TURBINE EQUIPMENT COMPANY

OF NEW ENGLAND

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New England Representatives for
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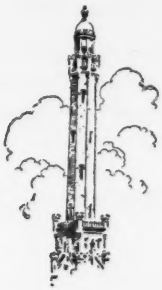
PURE WATER
. . BUILDER OF CITIES

Vacuum Chlorinators combat typhoid in CHICAGO

"In Chicago during the first nine months following complete chlorination of the water supply, which was accomplished in 1916, the death rate from typhoid fever was reduced by 71.44%." So the Joint Committee, Department of Health-Bureau of Engineering, in 1917 recorded this striking success in taming one of the most eccentric water supplies in North America.



And 113 additional W & T chlorinators sterilize Public and Private swimming pools, disinfect sewage and perform allied sanitary and industrial services in greater Chicago today

SINCE 1915 W&T chlorinators have helped in this fight. Twelve more in 1919, thirteen more in 1920.

Then, in 1923 Chicago installed its first W & T Vacuum chlorinator. So completely did this machine meet the exacting demands for dependable, trouble-free service, that 37 more Vacuum chlorinators were installed in 1924, 26 more in 1927 and 2 more in 1928. Eighty-five W&T VACUUM CHLORINATORS—85 expressions of confidence—wage war against water borne disease in Chicago today.

You can depend on W & T Vacuum Chlorinators. Technical Publication 38 will tell you why.

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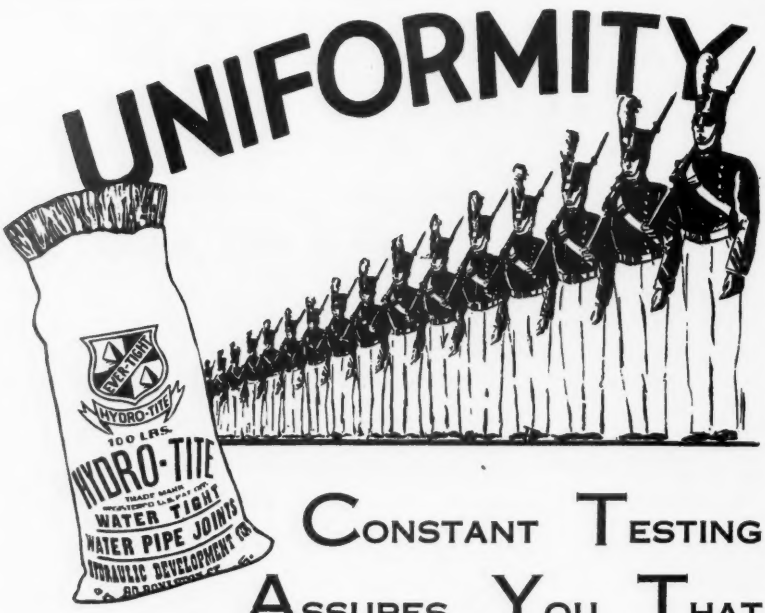
Manufacturers of
Chlorine and Ammonia Control Apparatus
Newark, New Jersey **Branches in Principal Cities**

"The Only Safe Water Is a Sterilized Water"

SA 39



CONSTANT TESTING ASSURES YOU THAT

WHEN you receive a bag of Hydro-Tite you receive 100 lbs. of material which is exactly like the last Hydro-Tite you used. Every manufacturing operation is carefully inspected and many of them checked by actual test. This care in compounding is only possible when a powdered material is made as we make Hydro-Tite.

Hydro-Tite joints are tight, strong and flexible. They are made without caulking — have a record of over 20 years and save from 50% to 75% as compared with lead. Write for information on any phase of joint making.

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A DEPENDABLE SELF-CAULKING JOINT COMPOUND

Main's Hotcoating for the inside of standpipes and water tanks, will stop all pitting and corroding, and is guaranteed for seven years.

Also

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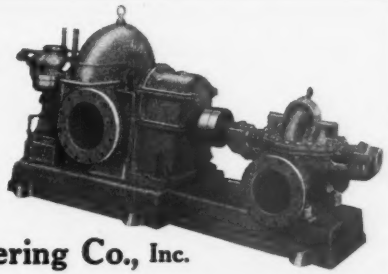
MURRAY TURBINE
MORRIS PUMP

For Towns having an Existing Boiler Plant



Starkweather Engineering Co., Inc.
BOSTON

The "COREY" Hydrant

Why you should use GENUINE COREY HYDRANTS

Water to Nozzles quicker than other Hydrants.

Standpipe can be removed and replaced without shutting off water in main.

Ease of operation insured by knuckle joint principle.

Only 13 turns to completely open or completely close, but full flow with only 4 turns.

Nozzles screwed in — not leaded.

Can be lengthened without shutting off water.

Will not flood if broken.

Positive Drip — cannot freeze.

Standpipe can be revolved quarter turns — Nozzles always in right direction.

Ask for our Catalog "G"

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New England Sales Manager, Lock Box 2, Northboro, Mass.

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TROY, N. Y.

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MANUFACTURERS
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CAST IRON PIPE

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Special Castings for Water and Gas.
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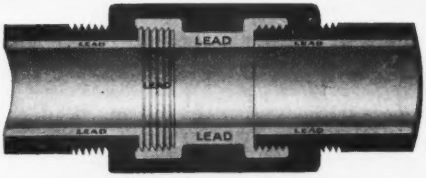
USE
MINERALEAD
For Jointing Bell and Spigot Water Mains

Easy handling, ingot form — Impervious to moisture — Absolute uniformity — Easy melting — Rapid pouring — No caulking — Less initial leakage — Bell holes unnecessary — A saving in cost of material and labor.

SEND FOR CATALOG

The Atlas Mineral Products Company
OF PENNSYLVANIA
MERTZTOWN Established 1892 PENNSYLVANIA

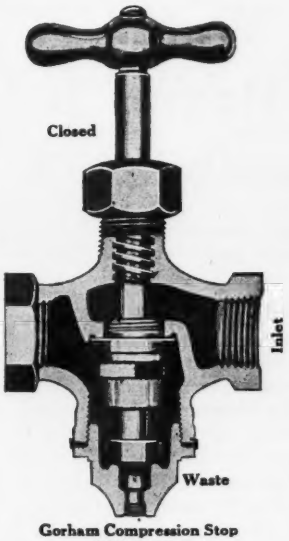
This shows Pipe just entering Lead Threads of Fitting



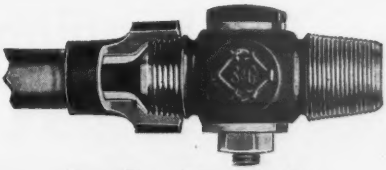
This shows Pipe Screwed into Lead Threads and Shoulder of Fittings

For Dependable Service Installations

"Wakefield Amalgamated"
Galvanized Lead Lined Iron Pipe and Fittings
Low Cost — Easily Installed — Permanent *Inquiries respectfully solicited*
LEAD LINED IRON PIPE CO., WAKEFIELD, MASS.



Gorham Compression Stop and Waste Cock



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S. & G. Water Works Brass Goods
S & D Heavy Pattern Slip Type Service Boxes
Byers' Wrought Iron Pipe
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Service, Roadway and Valve Boxes
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With Specially Adapted Lead-lined Fittings

Also Curb Cocks which eliminate Iron to Brass Corrosion both inside and out.

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MODERNIZED
HYDRANTS
Reg. U. S. Pat. Off.

FORESTALL TROUBLE

Rugged scientific design protects the Mathews Hydrant from the usual rusting, jamming, and leaking difficulties. Every moving part works on bronze. Only one thread ever needs oil. A compression-type main valve minimizes wear and leakage.

Mathews Hydrants, broken by traffic accidents, are repaired simply by unscrewing the damaged barrel and replacing it with another—a matter of minutes and of no digging.

Sixty-five years of hydrant-design have made the Mathews the national standard and the intelligent choice.

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ESTABLISHED IN 1803

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on each fire hydrant breakage repair

enough to pay for a new hydrant

FIGURES obtained from representative large, medium-size and small municipalities all over the country indicate that the total cost of repairing a broken fire hydrant, including *all* the items, such as excavating and repaving, which should be considered, averages about $75.00 and in many localities reaches $100.00.

This cost can be reduced to an insignificant amount, and striking aggregate savings can be made in your yearly fire hydrant repair expenses, by using

Kennedy SAFETOP Fire Hydrants.

These hydrants are fully as strong as any other hydrant on the market, but if struck by a smashing impact, the damage is strictly localized to a patented safety breakable section. The broken parts can be replaced in less than 15 minutes, by one man, without excavating or shutting off the water service, and at a total cost of $10.00.

This means that, as compared to the cost of repairing fire hydrants now commonly used, each *SAFETOP repair will save enough to pay for a new hydrant.*

Every water works superintendent should be posted on this important development. Write for full information on the Kennedy SAFETOP Fire Hydrant, how it can be adapted to existing hydrants at low cost, and its many exclusive advantages.

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THE STANDARD FOR 50 YEARS

Automatic Pressure Control Valves
Water Works Specialties

Altitude — Pressure Reducing — Surge
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Health and Protection First

Water delivered through dirty pipes
may be a MENACE.

Incrusted water pipes mean inefficiency
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We Guarantee the Results of Our
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CENTRIFUGAL, POWER, STEAM PUMPS

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OIL ENGINES

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Patent Automatic Cushioned Controlling Altitude Valves

We have enlightened many a water user in municipalities, in industrial plants and on railroads, as to the adaptability of these Golden-Anderson Valves, and as to their function of SAVING, and of eliminating troubles.

For automatically maintaining Uniform Stage of Water in Tank, Reservoir or Standpipes. Doing away with the annoyance of Freezing and Float Fixtures inside or outside of Tanks.

"Three Ways of Closing These Valves":

1st —Automatically, by water.
2nd—By Electricity, if desired.
3rd—By Hand

May also be arranged to automatically close when a break occurs in the mains. When necessary they may be so connected as to "work both ways" on a single line of pipe. No valves or fixtures inside or outside.

Sizes to 24 in.

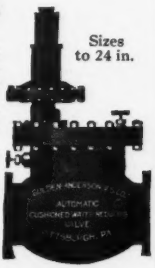
Remember!

"HOSTS OF REFERENCES"
Valves cushioned at all times by air and water
No water hammer or bursting mains

"Made with stop starter attachment for centrifugal pumps"

GOLDEN-ANDERSON
Pat. Automatic Cushioned Water Pressure Regulating Valves

1. Maintain a constant reduced pressure regardless of fluctuations on high pressure side.
2. Perfectly Cushioned by water and air. No metal-to-metal seats.
3. The best valve made for maintaining a constant low pressure where consumption is continuous.
4. Operates quickly or slowly as required — No attention necessary.
5. Positively no hammering or sticking.



Sizes to 24 in.

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Patent Automatic Cushioned Controlling Float Valves

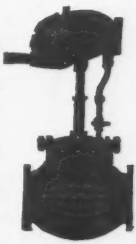
They carry a constant water level in feed water heaters by perfectly controlling the flow of makeup water.

Operated by protected enclosed copper float.

Cushioned by both air and water.

Operate without hammering, sticking or chattering. No metal-to-metal seats. Made angle or straightway.

Sizes 1 in. to 24 in.



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1. Automatically Maintain Uniform Water Levels in Tanks, Standpipes, etc.
2. Instantly Adjusted to Operate Quickly or Slowly.
3. Floats Swivel to any Angle — Most Satisfactory Float Valves Known.
4. No Metal-to-Metal Seats — No Water Hammer or Shock.
5. Cushioned by Water and Air.

Angle or Globe

Sizes to 24 in.

GOLDEN-ANDERSON
Patent Automatic Double Cushioned Check Valve

Sizes to 24 in. Angle or Globe

Automatically prevents reverse flow of pressure.

Perfectly cushioned to prevent shock or hammer.

Especially adapted for water works to prevent disastrous reverse flow of pressure due to pumps stopping.

Arranged so that quick or slow operating may be obtained.

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